RL/REG-99-04
January 20, 1999

REVIEW OF SEISMIC DESIGN CRITERIA USED AT SELECTED DOE HANFORD SITE NUCLEAR FACILITIES AND AT DOE WASTE VITRIFICATION PLANTS

Office of Radiological, Nuclear, and Process Safety Regulation of the TWRS Privatization Contractor

Richland Operations Office
P.O. Box 550
Richland, WA 99352

This page is intentionally blank.

RL/REG-99-04
January 20, 1999

REVIEW OF SEISMIC DESIGN CRITERIA USED AT SELECTED DOE HANFORD SITE NUCLEAR FACILITIES AND AT DOE WASTE VITRIFICATION PLANTS

Office of Radiological, Nuclear, and Process Safety Regulation of the TWRS Privatization Contractor

Richland Operations Office
P.O. Box 550
Richland, WA 99352

Approved: ______________________________

Date: ________________________________

PREFACE

The Department of Energy's (DOE) Richland Operations Office (RL) issued a request for proposal in February 1996 for privatized processing of waste as part of the Hanford Tank Waste Remediation System (TWRS). Offerors were requested to submit proposals for the initial processing of the tank waste at the Hanford Site. Some of this radioactive waste has been stored in large underground storage tanks at the Site since 1944. Currently, approximately 54 million gallons of waste containing approximately 250,000 metric tons of processed chemicals and 215 million curies of radionuclides are being stored in 177 tanks. These caustic wastes are in the form of liquids, slurries, saltcakes, and sludges. The wastes stored in the tanks are defined as high-level radioactive waste (10 CFR Part 50, Appendix F) and hazardous waste (Resource Conservation and Recovery Act).

Under the privatization concept, DOE intends to purchase waste processing services from a contractor-owned, contractor-operated facility through a fixed-price contract. DOE will provide the waste feedstock to be processed but maintain ownership of the waste. The contractor must: a) provide private financing; b) design the equipment and facility; c) apply for and receive required permits and licenses; d) construct the facility and commission its operation; e) operate the facility to process tank waste according to DOE specifications; and f) deactivate the facility.

The TWRS Privatization Program is divided into two phases, Phase I and Phase II. Phase I is a proof-of-concept/commercial demonstration-scale effort the objectives of which are to a) demonstrate the technical and business viability of using privatized contractors to process Hanford tank waste; b) define and maintain adequate levels of radiological, nuclear, process, and occupational safety; c) maintain environmental protection and compliance; and d) substantially reduce life-cycle costs and time required to process the tank waste. The Phase I effort consists of three parts: Part A, Part B-1, and Part B-2.

Part A is a twenty-month period to establish technical, operational, regulatory, and financial elements necessary for privatized waste processing services at fixed-unit prices. This includes identification by the TWRS Privatization Contractors and approval by DOE of appropriate safety standards, formulation by the Contractors and approval by DOE of integrated safety management plans, and preparation by the Contractors and evaluation by DOE of initial safety assessments. Of the twenty-month period, sixteen months is for the Contractors to develop the Part-A deliverables and four months is for DOE to evaluate the deliverables and determine whether to authorize Contractors to perform Part B. Part A culminated in DOE's authorization on August 24, 1998, of BNFL Inc. to perform Part B.

Part B-1 is a twenty-four month period to a) further the waste processing system design introduced in Part A, b) revise the technical, operational, regulatory, and financial elements established in Part A, c) provide firm fixed-unit prices for the waste processing services, and d) achieve financial closure.

Part B-2 is a sixteen year period to complete design, construction, and permitting of the privatized facilities; provide waste processing services for representative tank wastes at firm fixed-unit prices; and deactivate the facilities. During Part B-2, approximately 10% of the total Hanford tank wastes will be processed.

Phase II will be a full-scale production effort. The objectives of Phase II are to implement the lessons learned from Phase I and to process all remaining tank waste into forms suitable for final disposal.

A key element of the TWRS Privatization Program is DOE's regulation of radiological, nuclear, and process safety through the establishment of a specifically defined regulatory approach and a specifically chartered, dedicated Regulatory Unit (RU) at RL. This regulation is authorized by DOE through the document entitled *Policy for Radiological, Nuclear, and Process Safety Regulation of TWRS Privatization Contractors* (referred to as the Policy) and is implemented through the document entitled *Memorandum of Agreement for the Execution of Radiological, Nuclear, and Process Safety Regulation of the TWRS Privatization Contractors* (referred to as the MOA). The Policy is signed by the Under Secretary of Energy; the Manager, RL; the Assistant Secretary for Environment, Safety and Health (EH-1); and the Assistant Secretary for Environmental Management (EM-1). The MOA is signed by the Manager, RL; EH-1; and EM-1. The MOA details certain interactions among RL, EH-1, and EM-1 as well as their respective roles and responsibilities for implementation of the regulatory approach.

The authority of the RU to regulate the TWRS Privatization Contractor is derived solely from the terms of the TWRS Privatization Contract. Its authority to regulate the Contractor on behalf of DOE is derived from the Policy. The characteristics and scope of this special regulatory approach (special in the sense that it is based on terms of a contract rather than formally promulgated regulations) are delineated in the MOA, the TWRS Privatization Contract, and the following four documents, which are incorporated into the Contract and are part of the MOA.

> *Concept of the DOE Regulatory Process for Radiological, Nuclear, and Process Safety for TWRS Privatization Contractors*, DOE/RL-96-0005
>
> *DOE Regulatory Process for Radiological, Nuclear, and Process Safety for TWRS Privatization Contractors*, DOE/RL-96-0003
>
> *Top-Level Radiological, Nuclear, and Process Safety Standards and Principles for TWRS Privatization Contractors*, DOE/RL-96-0006
>
> *Process for Establishing a Set of Radiological, Nuclear, and Process Safety Standards and Requirements for TWRS Privatization*, DOE/RL-96-0004

Regulation by the RU in no way replaces any legally established external regulatory authority to regulate in accordance with their duly promulgated regulations nor relieves the Contractor from any obligations to comply with such regulations or to be subject to the enforcement practices contained therein.

In the execution of the regulatory approach through its regulatory program, DOE expects the RU to consider not only the relevant approaches and practices of DOE but also those of the Nuclear Regulatory Commission (NRC). The Policy states that

"It is DOE's policy that TWRS privatized contractor activities be regulated in a manner that assures adequate radiological, nuclear, and process safety by application of regulatory concepts and principles consistent with those of the Nuclear Regulatory Commission."

To this end, the RU interacts with the NRC (under the provisions of a memorandum of understanding with the NRC) during development of regulatory guidance and during execution of the regulatory program to ensure implementation of this policy.

This page intentionally left blank.

EXECUTIVE SUMMARY

Available information on the seismic design criteria used for other types of nuclear facilities at the U.S. Department of Energy's (DOE's) Hanford Site has been collected and reviewed. Additionally, the seismic design criteria of two other non-Hanford facilities with similar missions as Tank Waste Remediation System Privatization (TWRS-P) have been reviewed. They are the Defense Waste Processing Facility (DWPF) located at the Savannah River Site, and the West Valley Demonstration Project (WVDP) waste processing and storage facilities located at the Western New York Nuclear Service Center near West Valley, NY. This study is intended to aid in the review and acceptance of the seismic design criteria proposed for the TWRS-P Project, which will be located in the 200 East Area of the Hanford Site.

The requirements for the seismic design process to be used for this project were proposed by BNFL Inc. (BNFL) in the Safety Requirements Document (SRD) (BNFL-5193-SRD-01) accepted by the DOE Office of Radiological, Nuclear and Process Safety Regulation of the TWRS-P Contractor (Regulatory Unit) on March 27, 1998. The specific seismic design criteria to be used by BNFL in the application of this process will be developed in early 1999 using this approved process. This study provides historical perspective for the RU to use in its assessment of the proposed BNFL design, as well as information for other interested parties.

As discussed in this report, the seismic design criteria at the Hanford Site have changed over the past fifty years as more information on potential seismic hazard sources became known, as the methodology for estimating seismic hazard improved, and as seismic design requirements used for commercial and DOE nuclear facilities evolved. Particularly, the development of a consistent DOE Natural Phenomena Hazards (NPH) Policy in 1993, which advocates a risk-graded design approach, and the completion of a modern, site-specific Probabilistic Seismic Hazard Analysis (PSHA) in 1996, provided the necessary impetus for a recent re-evaluation of the seismic design criteria being used at the Hanford Site.

The DOE NPH Policy, as it evolved since its promulgation in 1993 and as presently stipulated in DOE Order 420.1 and associated standards, are reviewed in this study to provide an understanding of the graded approach. Seismic design requirements specified in the standards (e.g., DOE-STD-1020), that will assure desired target performance goals (i.e., probability of unacceptable performance) for structures, systems, and components (SSCs) with safety functions in reactor-type and nonreactor-type nuclear facilities, are discussed in light of the criteria used in the reviewed facilities. The DOE NPH policy requires the SSCs to resist progressively greater design basis earthquake (DBE) levels depending on their safety function and the severity of the potential hazards.

This study found that prior to the DOE NPH Policy, larger ground motion values, associated with a 5,000-year return period design basis earthquake, were used for seismic design of non-reactor nuclear facilities such as DWPF and the Hanford Waste Vitrification Project.

However, after the DOE NPH Policy was promulgated, for newer non-reactor facilities such as the Spent Nuclear Fuel (SNF) Project's Canister Storage Building (CSB) and the Cold Vacuum

Drying Facility (CVDF), a 2,000-year return period DBE, with lower ground motion, was specified. The CSB was designed to a higher ground motion of 0.35g (approximately 5,000-year return period) for reasons stated in the study. Additionally, the Hanford Site-specific PSHA study conducted in 1996 provided an acceptable engineering basis for the use of site-specific DBE response spectra, compared to the standardized response spectra developed for commercial nuclear power plants.

As indicated in this study, reactor facilities (e.g., FFTF, WNP-2) and non-reactor nuclear facilities (e.g., CVDF, waste tanks) at the Hanford Site have been designed (except CSB, as noted before) using various seismic design criteria. In most cases, the peak horizontal ground acceleration (PGA) of 0.25g was selected.

Based on the Hanford PSHA, the peak ground acceleration (PGA) corresponding to approximately a 2,000-year return period for the 200 Area is 0.26g. Using information from the nationally conducted seismic hazard study by the U.S. Geological Survey (USGS), and correcting for site conditions per the National Earthquake Hazard Reduction Program (NEHRP) Recommended Provisions for Seismic Regulations for New Buildings and Other Structures, the PGA for a 2,500-year return period is 0.27g. By interpolation, the USGS value for a 2,000-year return period PGA, corrected for site condition, is 0.23g. Thus, for a site located in the 200 East Area at Hanford, the estimated mean PGA for a 2,000-year return period can range from 0.23g to 0.26g. The significance of the 2,500-year return period is that this is the specified design basis earthquake in the 1997 NEHRP, and has been mentioned in the Nuclear Regulatory Commission (NRC) issue paper, *Consideration of Seismic Events for Integrated Safety Analysis of the Hanford Tank Waste Remediation System*, dated June 16, 1998, as being the minimum baseline criteria.

Considering the significant uncertainties inherent in earthquake hazard prediction, the above differences in ground motion level are essentially indistinguishable. From a more practical standpoint, the difference is unlikely to have any impact on design. Also, compliance with contractually-required risk tables (dose vs. event frequency) will be a consideration when establishing seismic requirements for structures, systems, and components required to prevent or mitigate the consequences of accidents from initiating seismic events. This may require certain SSCs to be designed to a higher ground acceleration.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

Over the last fifty years (1940s to date), many nuclear-related facilities have been built and operated at the U.S. Department of Energy's (DOE's) Hanford Site, located in south central Washington State. These facilities, which include nuclear reactors, nuclear material processing plants, and waste storage facilities, varied greatly in their operations and the type and quantity of nuclear material they handled. For these nuclear facilities, the earthquake, or seismic hazard, posed a potential challenge to the safe operation of the facility and to the safety of the workers, public, and the environment. Seismic design criteria used to provide adequate protection for these facilities continued to evolve with the significant increase in understanding of how to predict and estimate future earthquakes and mitigate their effects.

Most recently, DOE is considering the Tank Waste Remediation System-Privatization (TWRS-P) Project to process and vitrify liquid waste currently being stored at the Hanford Tank Farms. The TWRS-P Project is in the early stages of design, and will be constructed in the 200 East Area at the Hanford Site. Figure 1 shows the location of the Hanford Site within the state of Washington and the location of the 200 East Area at the Hanford Site. BNFL Inc. (BNFL) is the designated Privatization Contractor for this facility. In accordance with contractual requirements, BNFL submitted the Safety Requirements Document (SRD), which provides the seismic design process to be used in designing structures, systems, and components (SSCs) important to safety for the TWRS-P facility (BNFL 1998a). The requirements for this process were accepted on March 27, 1998, by the DOE Office of Radiological, Nuclear, and Process Safety Regulation of the TWRS-P Contractor (Regulatory Unit). The specific seismic design criteria to be used will be developed by BNFL in early 1999 using the approved process.

The DOE regulatory approach to radiological, nuclear, and process safety clearly places on the Privatization Contractor the responsibility to achieve adequate safety, comply with applicable laws and legal requirements, and conform to top-level safety standards and principles stipulated by DOE. The Regulatory Unit (RU) ensures that the Contractor achieves adequate safety; is complying with applicable laws and legal requirements; and is conforming to the DOE-stipulated top-level safety standards and principles.

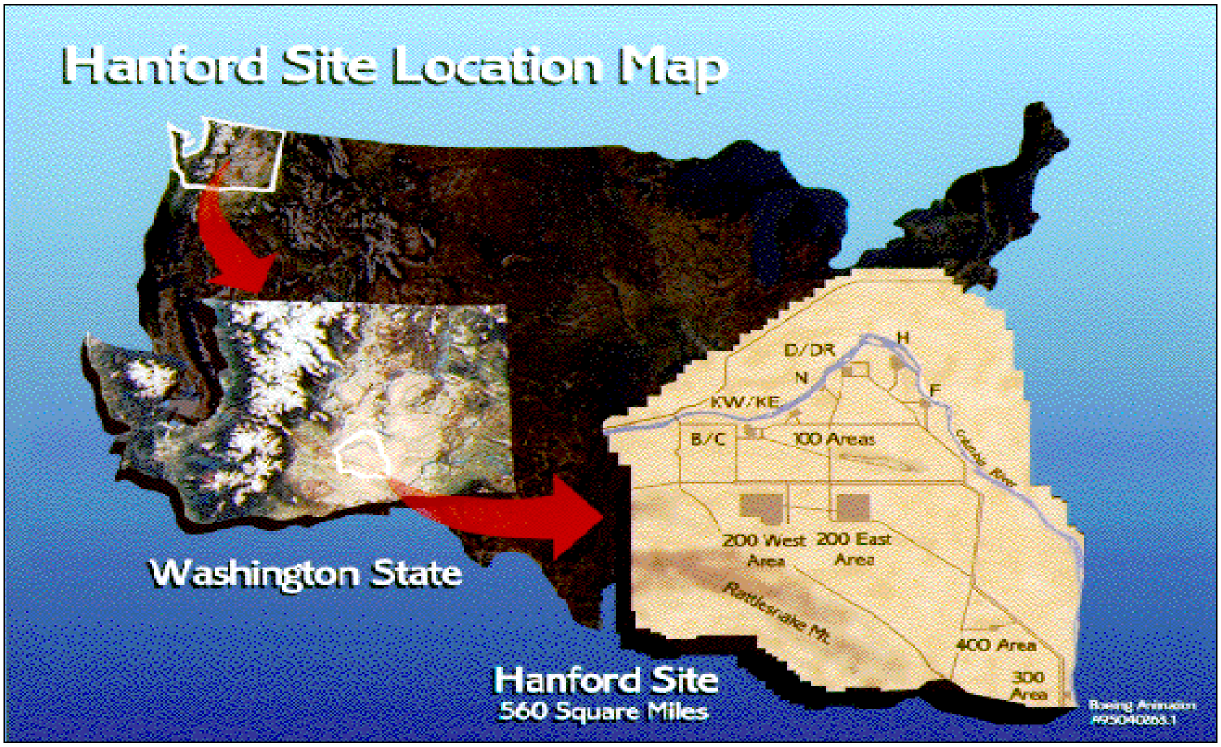


Figure 1. Location of 200 East Area and Hanford Site within the U.S.

The four documents that describe the DOE regulatory approach for the radiological, nuclear, and process safety regulation of the Privatization Contractor are:

- *Concept of the DOE Regulatory Process for Radiological, Nuclear, and Process Safety for TWRS Privatization Contractors*, DOE/RL-96-0005; Revision 0
- *DOE Regulatory Process for Radiological, Nuclear, and Process Safety for TWRS Privatization Contractors*, DOE/RL-96-0003; Revision 0
- *Top-Level Radiological, Nuclear, and Process Safety Standards and Principles for TWRS Privatization Contractors*, DOE/RL-96-0006; Revision 0
- *Process for Establishing a Set of Radiological, Nuclear, and Process Safety Standards and Requirements for TWRS Privatization,* DOE/RL-96-0004; Revision 0.

The TWRS-P project is not required to use DOE Natural Phenomena Hazards (NPH) Policy due to its unique charter to develop a design based on the following:

- Integrated Safety Management Principles

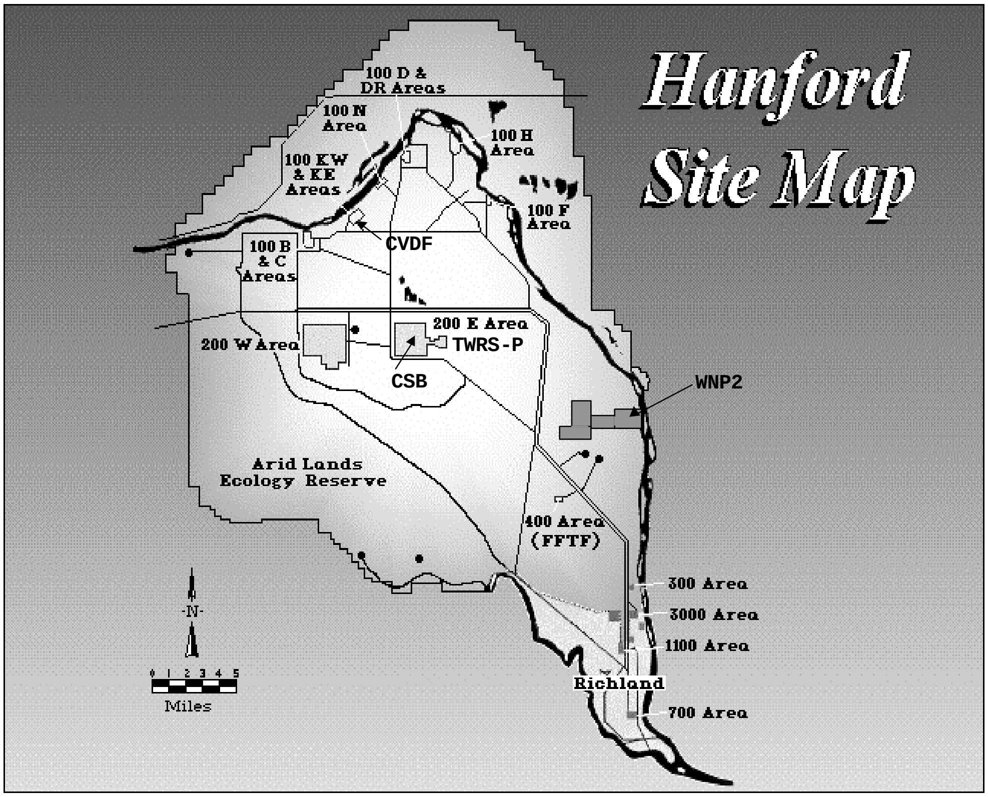
- Top-Level Standards
- Existing Regulations.

As part of the review process to examine the proposed seismic design criteria for the TWRS-P Facility, the RU initiated this study to compile available information on seismic design criteria used for selected nuclear facilities at the Hanford Site. Table 1 lists the major nuclear facilities considered for the present study, their age, and the facility type. A subset of these facilities has been chosen for additional study (shown in *italics* in Table 1) because they are of more recent design or because the perceived hazard and risk they pose to the public, workers, and the environment are either similar to or exceed those from the TWRS-P Project. Figure 2 shows the Hanford Site map with the location of the various areas listed in Table 1. This study is intended to provide perspective and background for subsequent DOE review of BNFL seismic design. Specifically, the RU must authorize construction of the proposed facility in FY 2001 and operations beginning in FY 2006. This study does not impose any requirements on BNFL.

DOE and U.S. Nuclear Regulatory Commission (NRC) seismic design criteria have been discussed in this report to provide a historical perspective and information for use in evaluating the TWRS-P seismic design criteria. The seismic design process to be used by BNFL for use on the TWRS-P project invokes, in part, the DOE seismic design approach defined in DOE-STD-1020 (series).

Table 1. Major Facilities Included in the Review of Seismic Criteria for the Hanford Site

Facility	**Design/ Construction Time Period**	**Remarks**
Chemical Plants, Canyons, and Reactors (100 and 200 Areas)	1940s – 1960s	Nuclear materials handling facilities at Hanford
N-Reactor (100N Area)	1960s	Reactor facility (seismic design criteria independently reviewed by the Atomic Energy Commission (AEC) Advisory Committee on Reactor Safety (ACRS) and the U.S. Geological Survey (USGS))
Fast Flux Test Facility (FFTF) (400 Area)	1970s	Reactor facility (seismic design criteria reviewed by NRC)
Washington Nuclear Power WNP-2 (near the 400 Area)	1977-1982	Operating commercial nuclear power plant located at the Hanford Site (designed to meet NRC seismic criteria. Later reviewed to evaluate beyond-design-basis seismic capacity)
Hanford Radioactive Waste Storage Tanks (200 Area)	1943-1986	Storage of high-level radioactive waste
Hanford Waste Vitrification Project (200 East Area)	1989-1993	Radioactive waste processing facility (construction terminated)
Canister Storage Building (200 East Area) *Cold Vacuum Drying Facility (100K Area)*	1995-present	Facilities to process and store spent nuclear fuel as part of the Spent Nuclear Fuel Project under construction)



In addition, two DOE facilities located at other sites have been selected for review because of their similarity in mission to TWRS-P. These facilities, listed in Table 2, include the Defense Waste Processing Facility (DWPF) located at the Savannah River Site in South Carolina, and the West Valley Demonstration Project (WVDP) located at the Western New York Nuclear Service Center near West Valley, New York.

Table 2. Additional Facilities Included in the Review of Seismic Criteria

Facility	Design/Construction Time Period	Type of Facility
DWPF, Savannah River Site, Aiken, South Carolina	Early 1980-1996	Operating radioactive waste processing facility
WVDP, West Valley, New York	1982-1995	Operating radioactive waste processing facility

Figure 2. Hanford Site Map Showing Areas and Locations of Various Facilities

Chapter 2 of this report presents an overview of the DOE Natural Phenomena Hazards (NPH) Policy to facilitate understanding of the material in the subsequent chapters. Chapter 3 provides a history of seismic criteria as they evolved at the Hanford Site. Chapter 4 contains an evaluation of the criteria used at selected facilities at the Hanford Site. Chapters 5 and 6 examine the seismic criteria used at DWPF and WVDP, respectively. Chapter 7 discusses the seismic criteria proposed in 1998 by BNFL for TWRS-P. Chapter 8 provides a summary of the seismic criteria used for the various facilities reviewed in this study. Appendix A lists the acronyms used in this report. Seismic-related terms are defined in the Glossary in Appendix B.

2.0 OVERVIEW OF DOE NPH POLICY

The DOE NPH Policy evolved from DOE Order 6430.1 to UCRL-15910 in 1985 and to the current DOE Order 420.1 with implementing Standards finalized in 1996. The Policy provides a graded approach for seismic design of DOE facilities to which it is applied. (The DOE NPH Policy is not a requirement for the TWRS-P Project, however.)

DOE's NPH Policy evolved over the years, as did seismic criteria at the Hanford Site. An overview of DOE NPH Policy is presented in this section to facilitate understanding of the seismic criteria presented later in this report. In the early 1980s, the guidance on seismic design was DOE Order 6430.1, *General Design Criteria* (DOE 1983). A systematic approach to instituting DOE NPH Policy originated in 1985 with the development of UCRL-15910, *Design and Evaluation Criteria for DOE Facilities Subjected to Natural Phenomena Hazard* (Kennedy 1990). Hazards covered in UCRL-15910 were earthquakes, extreme winds (including tornadoes), and floods. UCRL-15910 presented a graded approach, with SSCs being placed into one of four categories. The categories were called Usage Categories, and included General Use, Low Hazard, Moderate Hazard, and High Hazard. Criteria were presented for each category. The hazard was determined from probabilistic seismic hazard curves (plots of earthquake frequency or return period vs. ground motion values such as peak ground acceleration or response spectra ordinates), and deterministic methods were used to calculate structural response due to a postulated earthquake intensity. Performance goals assigned to each category were stated in terms of the annual probability of exceeding acceptable behavior limits, and ranged from $1x10^{3}$/year for General Use to $1x10^{-5}$/year for High Hazard. They provided a qualitative description of the expected behavior of SSCs. Building codes were used to estimate member capacities and detailing requirements. DOE NPH design and evaluation criteria in UCRL-15910 added safety factors and imposed limits on stresses and deformations so the performance goals would be met for each category. From 1985 to 1990, a draft of UCRL-15910 provided guidance. When it was published in 1990, UCRL-15910 provided a consistent basis for seismic design and evaluation of DOE facilities between 1990 and 1993.

In the early 1990s, DOE started a process of formalizing its NPH policy by developing DOE Order 5480.28, *Natural Phenomena Hazards Mitigation* (DOE 1993) and a set of technical standards. First, UCRL-15910 underwent extensive revision for conversion to DOE Standard 1020. Usage Categories in UCRL-15910 evolved into Performance Categories (PCs) in DOE Standard 1020, and requirements for each category were changed based on recent developments and new studies from the nuclear industry. Additionally, per DOE's direction, Brookhaven National Laboratory (BNL) assembled an expert panel to review the seismic analysis and design of high-level waste tanks. BNL's report, *Seismic Analysis and Design of High-Level Waste Tanks* (Bandyopadhyay 1995), also influenced the emerging seismic design and evaluation criteria. Documented comments from throughout DOE and from the Defense Nuclear Facilities Safety

Board (DNFSB) were reviewed, resolved, and incorporated. In January 1993, DOE Order 5480.28 was issued, followed by DOE Standard 1020 in April 1994, and subsequently revised in 1996 (DOE 1996). The technical basis for DOE Standard 1020 has been documented by Kennedy et al. (Kennedy, 1994). Other DOE Standards on performance categorization (DOE 1996a), site characterization (DOE 1996b), and hazard estimation (DOE 1996c) were also developed. DOE Order 5480.28 links all of these Standards together. As part of the DOE Order reduction program, DOE Order 5480.28 was assimilated into the new DOE Order 420.1, *Facility Safety* (DOE 1995a). An implementing Guide for DOE Order 420.1 was also developed (DOE 1995b), and the original Standards 1020 through 1023 remained as references in the DOE NPH Policy.

Performance categorization of SSCs, using DOE NPH Policy, is based on a graded approach, and is discussed in DOE-STD-1020, *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities*. The SSC may be placed in one of the following five PCs, as defined in DOE-STD-1020. Table 3 shows the type of seismic design criteria used for each PC. Additional guidance on placing SSCs into PCs can be found in DOE-STD-1021, (DOE 1996a). PC 4 criteria were established to approach criteria used by the NRC for commercial nuclear power plants. PC 1 and 2 criteria are essentially Building Code criteria for conventional facilities and essential facilities respectively. PC 3 was established to approximately achieve a performance goal between NRC commercial nuclear power plant criteria and building code criteria for essential buildings. An earthquake return period of 2000 years was derived for PC 3 considering the conservatism inherent in the building codes.

Table 3. Seismic Design Criteria Used for Each Performance Category

Performance Category	Criteria
PC 0	No Criteria (PC 0 was added during the conversion of UCRL-15910 to DOE-STD-1020)
PC 1	Building Code Criteria for Conventional Facilities
PC 2	Building Code Criteria for Essential Facilities
PC 3	Intermediate Criteria above Building Codes and below Commercial Nuclear Power Plant Criteria
PC 4	Approaching Criteria used for Commercial Nuclear Power Plants

Table 4 shows the target numerical and descriptive performance goals and the hazard frequency (mean seismic hazard exceedance frequency) for each performance category used to select the earthquake ground motion to achieve the performance goal. As listed in Table 4, the hazard frequency is set at a higher level than the performance goal for each PC. This was done to take into consideration the margin provided by using building code methods to determine the capacities of SSCs. Additional margin is provided by using standard response calculation methods.

Table 4. Hazard Frequencies and Performance Goals for each Performance Category

Performance Category	Hazard Frequency (Return Period)	Performance Goal	Performance Goal Description
1	$2x10^{-3}$ (500 years)	$1x10^{-3}$	Maintain occupant safety
2	$1x10^{-3}$ (1,000 years)	$5x10^{-4}$	Occupant safety; continued operation with minimal interruption
3	$5x10^{-4}$ (2,000 years)	$1x10^{-4}$	Occupant safety; continued operation; hazard confinement
4	$1x10^{-4}$ (10,000 years)	$1x10^{-5}$	Occupant safety; continued operation; high confidence of hazard confinement

Between 1985 and 1992, the hazard frequency used for Moderate Hazard (PC 3) was $1x10^{-3}$ (1,000-yr), and for High Hazard (PC 4) was $2x10^{-4}$ (5,000-yr). These evolved into the current criteria based on the results of a detailed study of seismic hazard curves across the U.S. and trends in commercial nuclear facility criteria. DOE seismic criteria in DOE-STD-1020 use a probabilistic definition of the seismic hazard, provide guidance on the selection of the Design Basis Earthquake (DBE), permit the use of deterministic structural response, and establish capacity and detailing criteria based on appropriate codes to meet the performance goal assigned to each PC. Criteria incorporate good practices and lessons learned from past earthquakes that have occurred worldwide.

A comparison is made in Table 5 between DOE seismic design criteria and NRC seismic design criteria used for nuclear power plants (NPPs). NRC criteria for power reactors are expected to be more conservative than NRC criteria to be developed for TWRS-P. Refer to DOE-STD-1020 or the Glossary of this report for a definition of the terminology used in Table 5.

Table 5. Comparison of NRC and DOE Seismic Design Criteria

	NRC	DOE Performance Category (PC)			
		1	2	3	4
Mean Hazard Exceedance Probability, P_H	$1x10^{-5}$ Median[1]	$2x10^{-3}$	$1x10^{-3}$	$5x10^{-4}$ ($1x10^{-3}$)[2]	$1x10^{-4}$ ($2x10^{-4}$)[2]
Response Spectra	Median amplification				
Damping for Structural Evaluation	Provided in RG1.61 (currently ASCE 4 levels)	5%		Table 2-3, DOE-STD-1020	
Acceptable Analysis Approaches for Structures	Dynamic analysis	Static or dynamic force method normalized to code level base shear		Dynamic analysis	
Analysis Approaches for Systems and Components	Dynamic analysis using in-structure response spectra	UBC-97 Force equation for equipment and non-structural elements		Dynamic analysis using in-structure response spectra	
Components Qualified by Test	TRS ≥ 1.1 RRS	No Requirement		TRS ≥ 1.4 RRS	
Importance Factor	Not Used	I = 1.0	I = 1.25	Not used	
Load Factors	Load factors of unity	Code specified load factors appropriate for structural material		Load factors of unity	
Scale Factors	Not used	Not Used		SF = 1.0	SF = 1.25
Inelastic Energy Absorption Ratios	Limit behavior to elastic response, ductile detailing not required	Accounted for by R_W from Table 2-2, DOE-STD-1020		F_μ from Table 2-4, DOE-STD-1020 by which elastic response is reduced to account for permissible inelastic behavior, ductile detailing	
Material Strength	Minimum specified or 95% non-exceedance in-situ values				
Structural Capacity	Code ultimate strength or limit-state level	Code ultimate strength or allowable behavior level		Code ultimate strength or limit-state level	
Quality Assurance Program	NQA-1	Required within a graded approach (from UBC-97 requirements for PC 1 to nuclear power plant requirements for PC 4)			
Peer Review	No explicit requirements	Not required	Required within a graded approach (from UBC-97 for PC 2 to nuclear power plant requirements for PC 4)		

[1]For NPP sites in the eastern US, this is equivalent to the 1 x 10^{-4} mean, for sites west of the Rockies.
[2]For sites such as Lawrence Livermore National. Lab., Sandia National. Lab.–Livermore, Stanford Linear Accelerator Center, and Lawrence Berkeley Laboratory, which are near tectonic plate boundaries.
(TRS = Target Response Spectra, RRS = Required Response Spectra)

DOE-STD-1020 was first issued in 1992, revised in 1994, and the current version issued in 1996. Some differences exist between DOE-STD-1020 and NRC practices for commercial nuclear plants. Differences exist in the following areas:

Input Ground Motion—DOE ground motion criteria (peak ground acceleration and response spectra) are specified using a mean hazard curve and a risk-graded hazard exceedance probability. NRC's criteria (Regulatory Guide 1.165, [NRC 1997]) for nuclear power plants are specified in terms of a median hazard curve and a hazard exceedance probability of 10^{-5} (which has been shown to be equivalent to a 10^{-4} mean exceedance probability in the central and eastern U.S. [NRC 1994]). In the western U.S., the relationship between median and mean probabiliites is slightly different. A compilation of the mean annual probability of exceeding the safe shut down earthquake (10^{-5} median hazard exceedance probability) for five western nuclear power plant sites indicates an average value of 2.0×10^{-4} [YMP 1997]. Thus, in regions of the U.S., NRC ground motion criteria is comparable to DOE ground motion criteria for PC4 facilities. For facilities to be licensed under 10 CFR 70 (TWRS-P would fall into this category), the NRC does not define a unique peak ground acceleration or associated return frequency. These would have to be selected and defended by the license applicant based on site design parameters and the hazard analysis (or integrated safety analysis in NRC terminology). The selected ground motion would also have to provide an acceptable level of risk (NRC 1998).

Damping—NRC damping values are essentially equal to DOE values up to the elastic limit. These values would be used for design of TWRS-P.

Inelastic Behavior—DOE allows limited inelastic behavior when ductile detailing requirements are provided. Specification of ductile detailing requirements produces a tougher structure. NRC limits design response to elastic behavior, but does not impose or credit ductile detailing requirements.

Equipment Qualified by Test—DOE uses a larger factor (1.4) than NRC (1.1) for amplifying the response spectra to achieve performance goals for equipment qualified by test.

Currently, the main difference between DOE and NRC criteria is in the treatment of inelastic behavior.

3.0 HISTORY OF SEISMIC CRITERIA USED AT THE HANFORD SITE

Seismic design bases for nuclear facilities at the Hanford Site have been evolving since the 1940s.

A review of available reports, memoranda, and viewgraph presentations on seismic criteria at Hanford (Conrads, 1988, 1990, 1994) was conducted. In addition, interviews were conducted with Hanford engineers cognizant of seismic analysis and design methodology. This information is presented chronologically. The data given in Tables 6 through 8 are summaries of site-specific seismic hazard studies performed and seismic criteria used in nuclear facility design.

3.1 Seismic Criteria Before 1989

Table 6 shows the original seismic design criteria used for construction in the 1940s to 1960s as well as criteria used for design of DOE and commercial reactors on site through 1989. The *Hanford Plant Standards on Design Criteria* was first issued in 1957, and was the initial source of site-specific seismic design criteria. Prior to 1957, appropriate provisions of the Uniform Building Code (UBC) were employed for seismic criteria. Seismic criteria during this period were bounded by a 0.25g horizontal peak ground acceleration and a variety of response spectra shapes used to model the frequency content of ground motion. The commercial nuclear power plant, WNP-2, was designed to meet NRC's evolving nuclear power reactor seismic design criteria, and licensed by the NRC in 1982. DOE seismic design criteria were in development, and draft DOE criteria in UCRL-15910 were available in the late 1980s. In 1989, the Hanford Plant Standard HPS-SDC-4.1 (HPS, 1989) was revised to incorporate seismic hazard characterization work conducted on site and DOE recommendations as represented by the draft UCRL-15910.

3.2 Seismic Criteria From 1989 to 1993

Table 7 presents a compilation of modern seismic hazard studies and seismic evaluations at Hanford from 1989 through 1993. During this period, DOE seismic design criteria continued to evolve, and were issued in January 1993 as DOE Order 5480.28. The Order invoked DOE Standards 1020, 1021, 1022, and 1023, all of which were still in draft form. In 1995, DOE Order 5480.28 was assimilated into DOE Order 420.1, and an implementing Guide for its use was issued. By 1996, all of the draft Standards had been finalized and issued. Thus, DOE NPH Policy, which includes seismic design criteria, was established. Hanford seismic design criteria were continuously updated to reflect changing DOE seismic design requirements. Additional site seismic hazard investigations and studies were conducted, and reflected increases in predicted seismic ground motions during the period. NRC criteria were also changing during this period with the revision of NRC Siting Criteria, as documented in 10 CFR 100 Appendix A and in Regulatory Guides on its implementation. NRC also conducted a program to examine commercial nuclear power plants' response to external events, including beyond-design-basis earthquake levels. The purpose of this program was to identify weak links in plants' seismic resistance. The program demonstrated that commercial power plants generally had a margin beyond their design basis. For example, WNP-2, designed using 0.25g-peak ground acceleration and Regulatory Guide 1.60, *Response Spectra*, was able to achieve seismic capacities of 0.43g.

In the early 1990s, the Hanford Waste Vitrification Project (HWVP) was started. This was designated as a high-hazard facility. Initially, the DBE was specified as 0.2g, corresponding to a return period of 5,000-year (Westinghouse Hanford Company [WHC] 1992a). During this time, DOE Standards on seismic design were in a constant cycle of revision as they were developed and published. New seismic hazard information also became available, and Hanford staff were unsure what the requirements of the final DOE NPH Policy would be. New seismic design criteria for Hanford were anticipated in the fall of 1993 (WHC, 1993). These factors led to the selection of a more conservative value of 0.35g peak ground acceleration in designing the HWVP in July 1993. The HWVP was subsequently terminated.

3.3 Seismic Criteria After 1993

In 1994, new ground motion values for design were issued for the 200 East and West Areas at Hanford. These values were based on a 1993 Probabilistic Seismic Hazard Analysis (PSHA) for Hanford.

In 1996, the Spent Nuclear Fuel (SNF) Project was initiated, and the partially constructed HWVP Canister Storage Building (CSB) became the location of the new SNF CSB. Although the CSB was categorized as a PC 3 facility, for cost and schedule considerations, the same seismic design criteria as the previous HWVP CSB, with 0.35g peak ground acceleration (PGA), were maintained. The CSB also underwent an NRC Equivalency review for its NPH design criteria, including seismic and extreme wind (Garvin, 1997). The Cold Vacuum Drying Facility (CVDF), a new facility, was also categorized as a PC 3 facility; however, seismic design criteria followed the 1997 Hanford Standard value of 0.26g, since it was a new construction project.

A summary of current seismic design criteria for Hanford (Conrads 1997) is presented in Table 8. This summary shows design values in the 1997 Hanford Standard HNF-PRO-97 (Conrads, 1997), which are consistent with DOE NPH Policy and are obtained from the 1996 Hanford PSHA (Geomatrix, 1996). For comparison, values from the 1997 UBC and the 1997 Seismic Provisions of the National Earthquake Hazards Reduction Program (NEHRP, 1997) are also presented. The 1997 UBC values are based on older seismic hazard maps for the entire United States. NEHRP values are also based on U.S. maps, but are developed by the U.S. Geological Survey (USGS) and include recent data and methodology.

Table 6. Seismic Design Criteria for Chemical Plants, Canyons, and Reactors at Hanford (1940–1989)

Time Frame	Facility	Criteria	Comments
1940s – 1960s	Chemical Plants, Canyons, and Reactors	UBC (Pre-1957), Hanford Plant Standard (Post-1957)	
1960 – 1962	N-Reactor	UBC + 0.20g PGA	Internal reviews by AEC/ACRS and independent review by USGS for 0.25g PGA (1965 & 1967)
1971 1978	FFTF (Blume Study)	0.25g PGA Hor+Site-Specific Spectra, 0.17g PGA Ver+Site-Specific Spectra	Not licensed by NRC, but NRC issued a Safety Evaluation Report (SER)
1976 – 1980	Pacific Northwest Laboratory (PNL) Regional Study, USGS Study	0.25g PGA	Hazard study
1977 – 1982	WNP-2 (Commercial Nuclear Power Plant), NRC SER	0.25g PGA (MMI VIII, ~ 10,000-yr) Safe Shutdown Earthquake (SSE) + Regulatory Guide (RG) 1.60 Spectra	6.5 Magnitude Earthquake, Woodward-Clyde Follow-on Hazard Study
1979	LLNL/TERA Study	0.25g PGA	Hazard study for DOE sites (TERA, 1981)
1988	B-Plant (200 East) Re-evaluation	0.28g (5,000-year),0.25g (4,000-year), 0.20g (2,500-year)	Re-evaluation of facility
1989	Site Seismic Design Criteria 100/200 Area Hanford Plant Standard, (HPS, 1989)	0.20g PGA (5,000-year), 0.12g PGA (1,000-year), Newmark-Hall (N-H) Median Soil Spectra (Newmark 1978)	Based on Woodward-Clyde 1989 study and UCRL-15910

Table 7. Modern Seismic Hazard Studies and Seismic Evaluations at Hanford

Time Frame	Facility	Criteria	Comments
1990	Hanford Radioactive Waste Storage Tanks seismic reevaluation	0.25g PGA Hor + FFTF Spectra	Facility seismic review
1990s	Hanford Waste Vitrification Project	0.35g Horizontal, 0.23g Vertical, N-H Spectra	Higher PGA (than existing standards) used to envelop any anticipated change to the existing Hanford Standard from ongoing site-specific PSHA studies and evolving DOE Standard 1020
1992	WNP-2	0.25g PGA	Geomatrix Study to reassess seismic hazard
1994	200 East and 200 West	0.35g PGA PC 4, 0.20g PGA PC 3, 0.15g PGA PC 2 Hanford Standard Spectra	Based on 1993 Geomatrix PSHA and evolving DOE criteria
1995	WNP-2 Independent Plant Evaluation for External Events (IPEEE) Review	0.50g PGA Review Level Earthquake	IPEEE submitted to NRC, capacity = 0.43g

Table 8. Present-Day Seismic Design Criteria for Hanford

Time Frame	Location	Criteria	Comments
1996	SNF/Canister Storage Building (200 East Area)	0.35g PGA Hor, 0.23g PGA Ver + N-H Spectra	Used higher than PC 3 (0.24g) criteria since modification of partially constructed HWVP/CSB
1996	SNF/CVDF (100 Area)	0.26g PGA Hor PC 3, 0.18g PGA Ver + Geomatrix UHS	Based on 1996 Geomatrix PSHA
1997 Current Hanford Standard	Site Seismic Design Criteria Revised (100/200Area)	0.48g PGA Hor PC 4, 0.37g PGA Ver + Spectra, 0.26g PGA Hor PC 3, 0.18g PGA Ver + Spectra	Based on 1996 Geomatrix PSHA results following DOE criteria, (Conrads 1997)
1997 Current Hanford Standard	(300/400 Area)	0.37g PGA Hor PC 4, 0.27g PGA Ver +Spectra 0.21g PGA Hor PC 3, 0.14g PGA Ver +Spectra	Based on 1996 Geomatrix PSHA results following DOE criteria, (Conrads 1997)
1997 UBC	Hanford	0.20g PGA + Spectra	Zone 2B
1997 NEHRP	Hanford Reservation	0.20-0.25g PGA (2,500-year), 0.10-0.15g PGA (1,000-year), 0.09-0.10g PGA (500-year)	From latest USGS Seismic Hazard Map, see Figure 5
Historic Record	Hanford Reservation	~ 0.05g PGA (calculated)	Milton-Freewater 1936 Earthquake

Current Hanford seismic hazard curves (Conrads 1997) for various areas are shown in Figure 3.

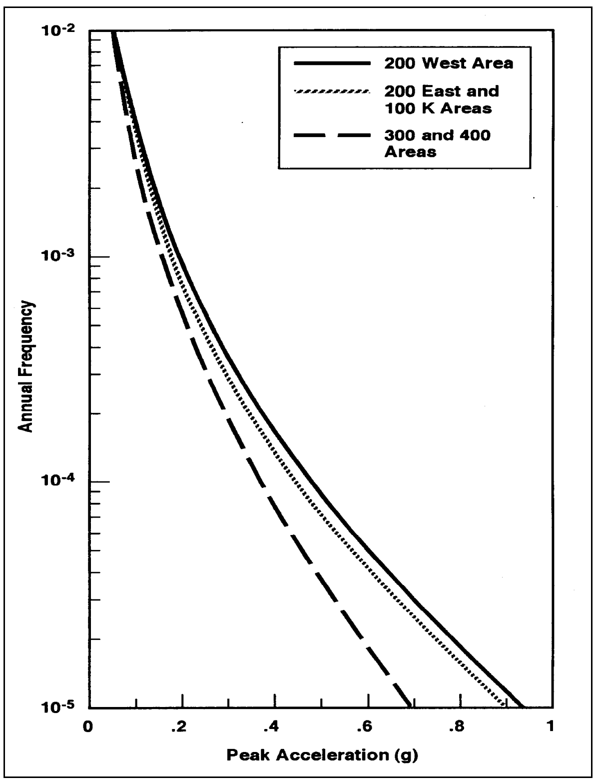


Figure 3. Mean Hanford Seismic Hazards Curves for Different Areas (based on Geomatrix 1996)

A comparison of 5%-damped horizontal response spectra used at the Hanford Site in 1993 (WHC, 1993) and 1997 (Conrads, 1997) and the NEHRP 1997 spectrum corrected for Hanford site conditions is shown in Figure 4. Also shown are the corresponding WPN-2 and NRC Regulatory Guide 1.60 spectra (NRC, 1974).

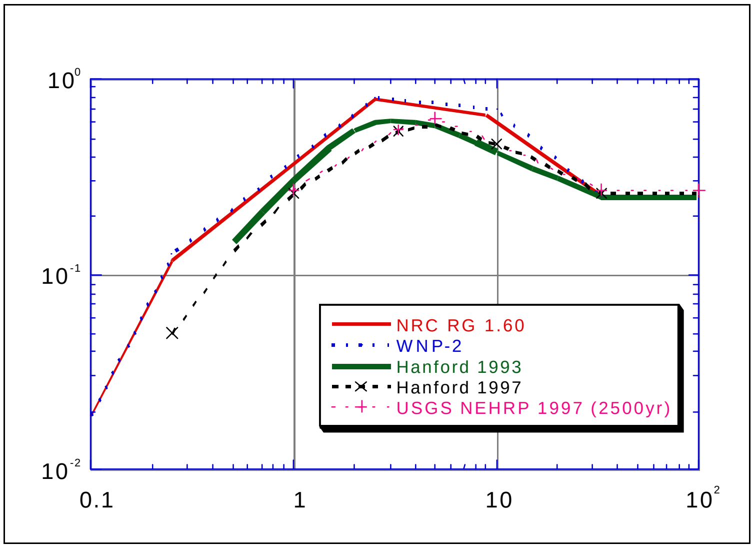


Figure 4. Comparison of Response Spectra used at Hanford (Horizontal, 5%-damped)

Hanford Standard design ground motion values for the 100K, 200E, 200W, 300, and 400 Areas are based on the 1996 Geomatrix seismic hazard analysis report prepared for the WHC (Geomatrix 1996) and the 1997 Hanford report, Engineering Design and Evaluation, prepared by Numatec Hanford Corporation for the Project Hanford Management Contractor (Conrads 1997).

Table 9 lists the peak horizontal ground accelerations for the five areas that were produced by the 1996 Geomatrix study and the values recommended by Project Hanford for on-site seismic design. The 1997 report used the upper bound of the Geomatrix values for the 100K, 200E, and 200W Areas and reported one value for the 100 and 200 Areas. Similarly, one value was reported for the 300 and 400 Areas.

Table 9. Comparison of PGA Values (in g) for Hanford Areas from the 1996 Geomatrix Report and the 1997 Hanford Report

	1996 Geomatrix Report*		**1997 Hanford Report****	
Area	**PC 3**	**PC 4**	**PC 3**	**PC 4**
100K	0.24	0.45	0.26	0.48
200E	0.24	0.44	0.26	0.48
200W	0.26	0.48	0.26	0.48
300	0.21	0.37	0.21	0.37
400	0.21	0.37	0.21	0.37

*****Reported values for all five Areas.
******Only reported values for 100/200 Areas and 300/400 Areas.

Figure 5 shows a recent USGS map of the Washington and Oregon area for earthquake PGA at a 2% probability of occurrence in 50 years (i.e., a 2500-year return period). The Hanford Site is located at about 46.3° latitude and -119.3° longitude. This indicates an earthquake PGA of 0.20-

0.25g in the Hanford area for sites with shear wave velocity of 2494 ft/sec (760 m/sec). The PGA can also be obtained by specifying the zip code of Richland, which gave 0.23g for the site. The shear wave velocity in the 200E Area is approximately 1300 ft/sec. Correcting the USGS value to the 200E site conditions results in a value of 0.27g for the 2,500-year earthquake. Interpolation to the PC 3 level (2,000-year) and correction for site conditions would yield a 0.23g PGA at Hanford 200E Area (NEHRP 1997).

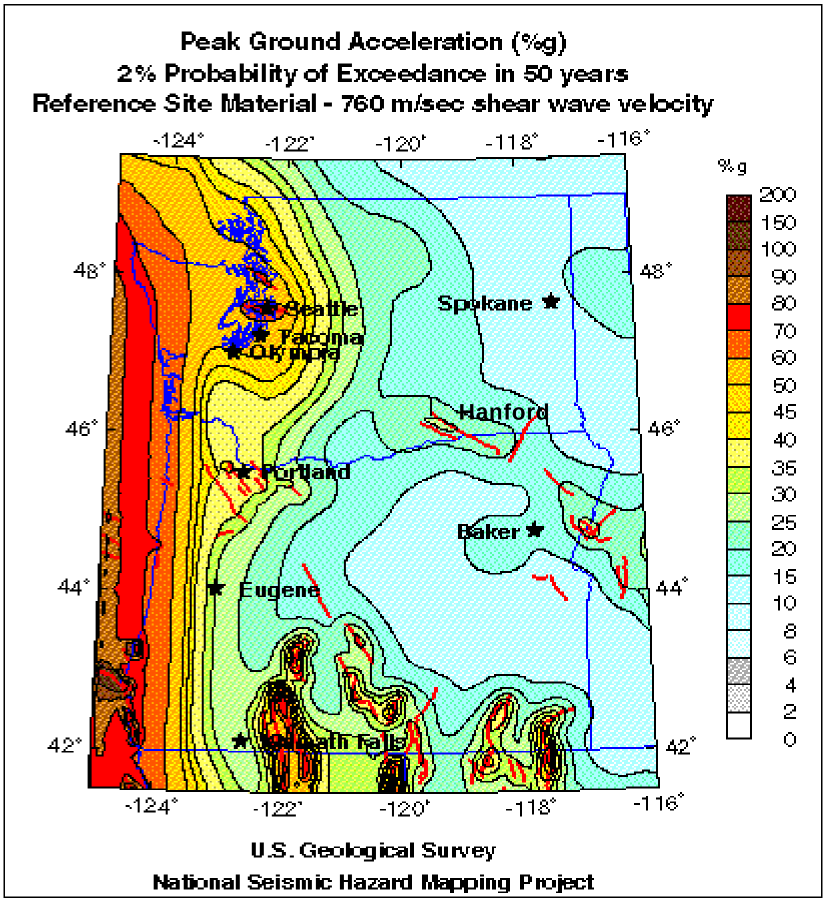


Figure 5. 1997 USGS Map of Washington and Oregon for 2% Probability of Exceedance in 50 Years (Approximate Return Period of 2,500 Years) of PGA *(Courtesy USGS)*

3.4 Historic Seismicity

The rate of historic seismicity during the last 150 years has been low in the Hanford area. An earthquake occurred in Umatilla, Oregon in 1893, and was estimated to have a Modified Mercalli Intensity (MMI) of VI. The historic earthquake for the Hanford Site was the magnitude 5.8 Milton-Freewater earthquake of 1936, which produced an estimated on-site peak ground acceleration of less than 0.05g.

4.0 SEISMIC CRITERIA USED FOR SELECTED FACILITIES AT HANFORD

Selected facilities at Hanford have been designed to various criteria, with PGAs from .20 - .35g.

Criteria used for the seismic design of reactors in the 1970s are summarized in Sections 4.1 and 4.2. Section 4.3 discusses seismic evaluation of waste storage tanks. Sections 4.4, 4.5, and 4.6 discuss non-reactor nuclear facilities designed during the 1990s as DOE NPH criteria were evolving.

4.1 Washington Nuclear Power Unit 2 Reactor

The Washington Public Power Supply System operates WNP-2, a 3,323-megawatt (thermal) General Electric boiling water reactor (BWR) located near the 400 Area of the Hanford Site. Seismic design of the facility used an SSE of 0.25g peak horizontal ground acceleration (WPPSS 1986, 1994) and RG 1.60 response spectra (NRC 1974). The hazard was based on probabilistic estimates conducted by Woodward-Clyde Consultants in 1980 and 1981. At that time, the 0.25g-peak ground acceleration was thought to have a return period of greater than 10,000 years. NRC produced an SER during the period 1977-1982 that accepted this definition of the SSE.

As part of NRC's IPEEE program, WNP-2 was shown to have a seismic capacity of 0.43g (based on the High Confidence Low Probability of Failure [HCLPF] seismic capacity) in 1995.

4.2 Fast Flux Test Facility (FFTF)

John A. Blume & Associates conducted comprehensive site geological and seismological studies for the FFTF, and produced a summary report entitled *Seismic Evaluations and Development of Ground Acceleration and Response Spectra for FFTF* in February 1971 (Blume 1971). The SSE used for the design had a peak ground acceleration of 0.25g and site-specific response spectra. A modified El Centro earthquake time history was also used to conduct the design analyses. This was based on a postulated magnitude 6.8 earthquake in Rattlesnake Mountain, 9.5 miles from FFTF. FFTF was not licensed by NRC, but NRC reviewed the assessment and issued an SER, NUREG-0358, in August 1978.

Dynamic analyses were conducted during the design phase using Regulatory Guide 1.61 damping values (NRC 1973) and soil structure interaction. Some equipment items were qualified by testing. Seismic design employed industry standards, non-mandatory guidance from the NRC for light water reactors, NRC Regulatory Guides, the NRC Standard Review Plan, and NRC Information Notices.

4.3 Hanford Site Radioactive Waste Storage Tanks

(NOTE: The document, *Summary Status on the Seismic Evaluation of Hanford Site Radiological Waste Storage Tanks*, (WHC 1990) was used to prepare this section.)

Radioactive waste resulting from the chemical processing of spent nuclear fuel has been accumulating at the Hanford Site since 1944. This waste is stored in underground waste storage tanks. Five basic tank designs are used at the Hanford Site. Four of these designs are single-shell; the fifth is a double-shell tank design.

One hundred forty-nine single-shell tanks (SSTs) were constructed between 1943 and 1964. These tanks are buried in 12 separate tank farms. One hundred thirty-three of the SSTs are 75 ft. in diameter, with nominal capacities of 500,000 to 1,000,000 gallons. Sixteen of the tanks are smaller units of a similar design, with a 20-ft. diameter and a capacity of 55,000 gallons. The large SSTs are made of reinforced concrete, and are cylindrical in shape and dome-roofed, with a single layer of steel lining the bottom and side walls.

Twenty-eight double-shell tanks (DSTs) were constructed between 1968 and 1986. These tanks are buried in six separate tank farms. DSTs have a nominal capacity of one million gallons. DSTs are 80 ft. in diameter, and made of reinforced concrete. They are cylindrical in shape, have domed roofs, and are composed of a primary steel tank and a secondary steel liner. The primary steel tank consists of a floor, a cylindrical shell 75 ft. in diameter, and a dome that is integral with the reinforced concrete dome. The primary tank provides containment for liquid waste. The secondary steel liner acts as a redundant leakage barrier for containing liquid waste. There is a nominal 30-inch air gap between the primary steel tank and the lined, reinforced concrete tank wall. The SST and DST tank farms are located on the Hanford Site in the 200 East and 200 West Areas.

As indicated in Section 4.2, seismotectonic studies completed for the design and construction of the FFTF provided the basis for constructing a Hanford site-specific seismic design response spectra anchored at 0.25g peak horizontal ground motion (Blume 1971). FFTF seismic design criteria were incorporated into Hanford Plant Standards in November 1973. All double-shell waste tank analytical evaluations used FFTF response spectra.

The waste tanks are buried in soil that ranges in texture from sandy fine gravel to coarse sand. Excavated sediment was used as backfill in constructing the tanks. The water table or zone of saturation ranges from about 200 to 300 ft. beneath ground surface. Liquefaction of foundation materials during a seismic event is not considered to be a credible scenario because of the relatively coarse texture and density of the soil and the significant depth of the water table. Results of the study are listed below:

Single-Shell Tank seismic evaluations

- The 10 tanks in 241-A and 241-AX (75 ft. diameter, 1,000,000-gallon capacity) have been seismically qualified to 0.25g.

Double-Shell Tank seismic evaluations

- The lined, reinforced concrete tank and dome and the primary steel liner have been analytically demonstrated to meet the 0.25g spectra for all tanks except the tanks in 241-AY.

- The primary steel liner of tanks in 241-AY has been analytically demonstrated to meet the seismic input spectra anchored to 0.25g.

- Most of the key structural components of the tanks in AY are similar in design to the other DSTs, and were judged to be seismically qualified to current seismic input spectra (WHC 1990).

- Some of the key components of the ventilation systems in 241-AY and 241-AZ have been seismically qualified by analysis.

4.4 Hanford Waste Vitrification Project

4.4.1 Background

In the early 1990s, the HWVP was established to design and construct a vitrification facility at the Hanford Site. This facility would vitrify high-level radioactive waste stored in underground tanks in the 200 East and 200 West Areas into glass logs, and would provide interim storage of the logs until final disposition in a permanent repository. This interim storage building, designated as the CSB, was designed and partially constructed in the northwest corner of the 200 East area. The project was terminated in 1993.

The material reviewed to summarize the HWVP seismic criteria includes the following:

- *Hanford Waste Vitrification Plant Functional Design Criteria* (WHC 1992)

- *Hanford Waste Vitrification Plant Canister Storage Building Preliminary Safety Analysis Report* (WHC 1992a).

4.4.2 Seismic Hazard

The HWVP was classified as a High Hazard facility. HWVP seismic design response spectra were based on guidance in UCRL-15910. At the time the HWVP was being designed, the guidance for High Hazard facilities (i.e., earthquake return period similar to, but lower than, PC 4) was to use the 5,000-year earthquake and the Newmark-Hall median spectral amplifications. Moderate Hazard guidance (i.e., earthquake return period similar to, but lower than, PC 3) was to use the 1,000-year ground motion. The HWVP CSB Safety Class 1 SSCs were designed to the highest performance goal, High Hazard. This resulted in a Newmark-Hall median response spectrum anchored at 0.20g. The anchor was based on the 5,000-year ground motion from the 1989 seismic hazard assessment *Seismic Hazard Assessment for Hanford DOE Site*, WHC-MR-0023 (Woodward-Clyde Consultants 1989). This assessment applied Washington Public Power Supply System's seismic hazard sources and methodology to Hanford Site locations (Coppersmith, et al. 1981).

During the design phase of the HWVP, the Washington Public Power Supply System began a new seismic hazard assessment in support of its IPEEE submittal, and consulted Hanford seismology and geotechnical staff for review and information. WHC soon proceeded to revise their seismic hazard assessment. Further, it was important that the two major facilities produce complete, up-to-date seismic hazard assessments. The seismic sources used in these studies are shown in Figure 6.

In the early phase of the seismic hazard assessment revision process, two changes occurred that resulted in modification to the HWVP seismic design. First, the seismic hazard was deemed to be higher than 0.2g, and second, the draft of proposed revisions to UCRL-15910 recommended a 10,000-year return period for the highest performance category, High Hazard, which became PC 4.

HWVP management made the conservative decision to remain in the highest performance goal category, follow the 10,000-year ground motion recommendation, and use the draft value of the in-progress seismic hazard assessment. This resulted in the development of a median Newmark-Hall spectral shape anchored at 0.35g.

An important difference between DOE-STD-1020 and UCRL-15910 is that the seismic design requirements were increased for both the highest and next-highest categories (High Hazard/PC 4 and Moderate Hazard/PC 3). In DOE-STD-1020, the specified requirements of PC 3 are between those of the former High Hazard and Moderate Hazard categories.

4.4.3 Seismic Design Criteria

SSCs were classed using a four-tier safety classification (safety class 1, 2, and 3, and non-safety class) outlined in a manual issued by WHC. Safety class 1 was equivalent to "safety class" or "safety class item," as indicated in DOE Order 6430.1A. The design of SSCs was to be based on the *Standard Architectural Civil Design Criteria for Design Loads for Facilities*, HPS-SDC-4-1 (HPS 1989). All safety-class (1, 2, and 3) items were required to withstand DBEs as defined in HPS-SDC-4-1 for the respective safety class. For non-safety class, the Uniform Building Code was specified.

4.5 Canister Storage Building

4.5.1 Background

To alleviate one of the most pressing safety and environmental issues at the Hanford Site, the decision was made in 1994 to expeditiously move N-Reactor SNF stored in the 100 K-East and K-West storage basins to a new storage facility. This was to safeguard against deteriorating SNF, which was already releasing radioactive material into the basin water, from leaking into the environment because of aging or seismically underdesigned storage basins. After various studies were conducted, the previously abandoned, partially constructed HWVP CSB provided the best solution with respect to cost and schedule for removing SNF from the K-Basins. The CSB is composed of below-grade concrete vaults to store SNF packed in Multi-Canister Overpacks (MCOs). The MCOs are lowered into the vault from a concrete operating deck atop the vault after the fuel has been vacuum-dried in the CVDF.

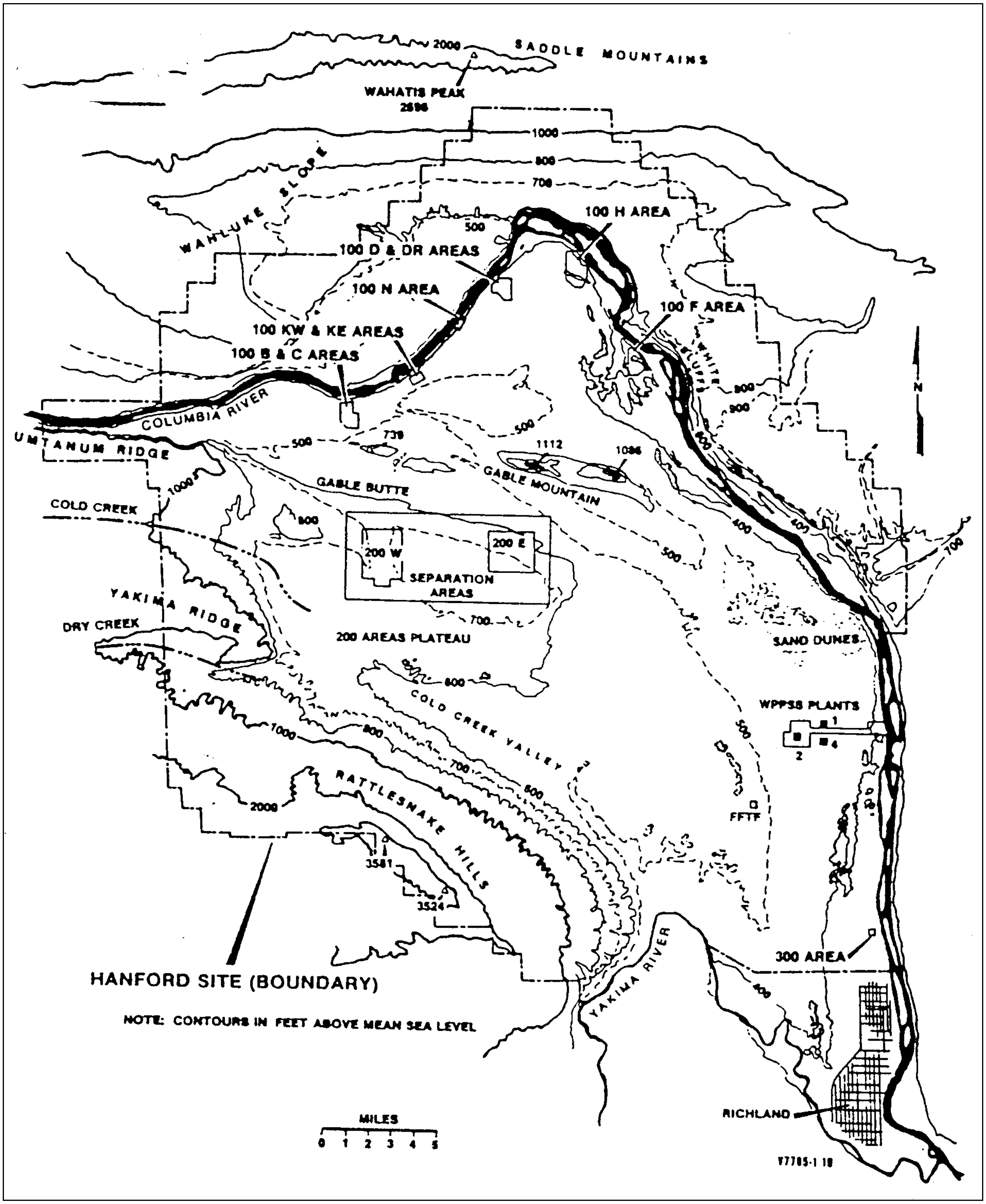


Figure 6. Seismic Sources and Topography of the Hanford Site

CSB design began in the 1994-1995 time period; construction of the facility, which commenced in 1996, is still in progress. Material reviewed to summarize CSB seismic criteria includes the following:

- *Canister Storage Building Safety Analysis Report* Phase 3, WHC-SD-SNF-RPT-004, Revision 7 (WHC 1996)

- *Canister Storage Building Natural Phenomena Hazards*, WHC-SD-SNF-DB-009, Revision 4 (WHC 1996a)

- *Spent Nuclear Fuel Project Seismic Design Criteria*, NRC Equivalency Evaluation Report WHC-SD-SNF-DB-004, Revision 2A (WHC 1996c).

4.5.2 Seismic Hazard

Current seismic hazard information for the Hanford Site is obtained from the 1996 PSHA for the DOE Hanford Site, prepared by Geomatrix (Geomatrix 1996). This study incorporates seismotectonic data and interpretations that are more current than the hazard assessment for the WNP-2 Reactor. According to this report, the potential seismic sources that are major contributors to the seismic hazard are the crustal sources and Cascadia Subduction Zone earthquakes in western Washington State.

Mean (as well as other percentile) seismic hazard curves for various areas at the Hanford Site are presented in the Geomatrix report. The crustal sources dominate the hazard for short and intermediate motions (PGA and 0.3-second spectral accelerations), while the Cascadia interface source is the largest contributor to the long-period hazard for low ground-motion levels. For the area surrounding the CSB site, the mean hazard curve is given in Figure 7. Based on the mean hazard curve, ground motion levels for different return periods for the 200 East Area were computed in the report. Figure 8 shows equal hazard response spectra for horizontal (PGA 0.24g) and vertical (PGA 0.16g) ground motions for a 2,000-year return period, which is the target seismic hazard exceedance probability for Performance Category 3, as specified in DOE-STD-1020.

4.5.3 Seismic Design Criteria

SSCs were originally grouped with a four-tier classification (safety class 1, 2, and 3, and non-safety class), which was subsequently revised to reflect the classification methodology in DOE-STD-3009-94 (DOE, 1994); i.e., safety-class, safety-significant, and non-safety-class. For safety-class SSCs, seismic criteria (PGA and response spectra) for PC 3 was considered to be applicable. However, SNF project management decided to use the partially completed HWVP CSB structure for the SNF CSB. HWVP's design was evaluated for a Newmark-Hall median horizontal seismic spectra anchored at 0.35g. These spectra are shown in Figure 8 (identified as the CSB horizontal and vertical). Clearly, these CSB spectra bound the PC 3 spectra. Although a WHC study (WHC 1996) concluded that designing the CSB to DOE criteria as a PC 3 facility provides an acceptable level of safety, more stringent criteria than PC 3 criteria were adopted when CSB construction resumed in the SNF project phase.

For safety-significant SSCs, seismic criteria specified in the CSB Safety Analysis Report (SAR) correspond to safety class 2, which are approximately equivalent to Uniform Building Code (ICBO 1997), Zone 2B criteria (WHC 1996).

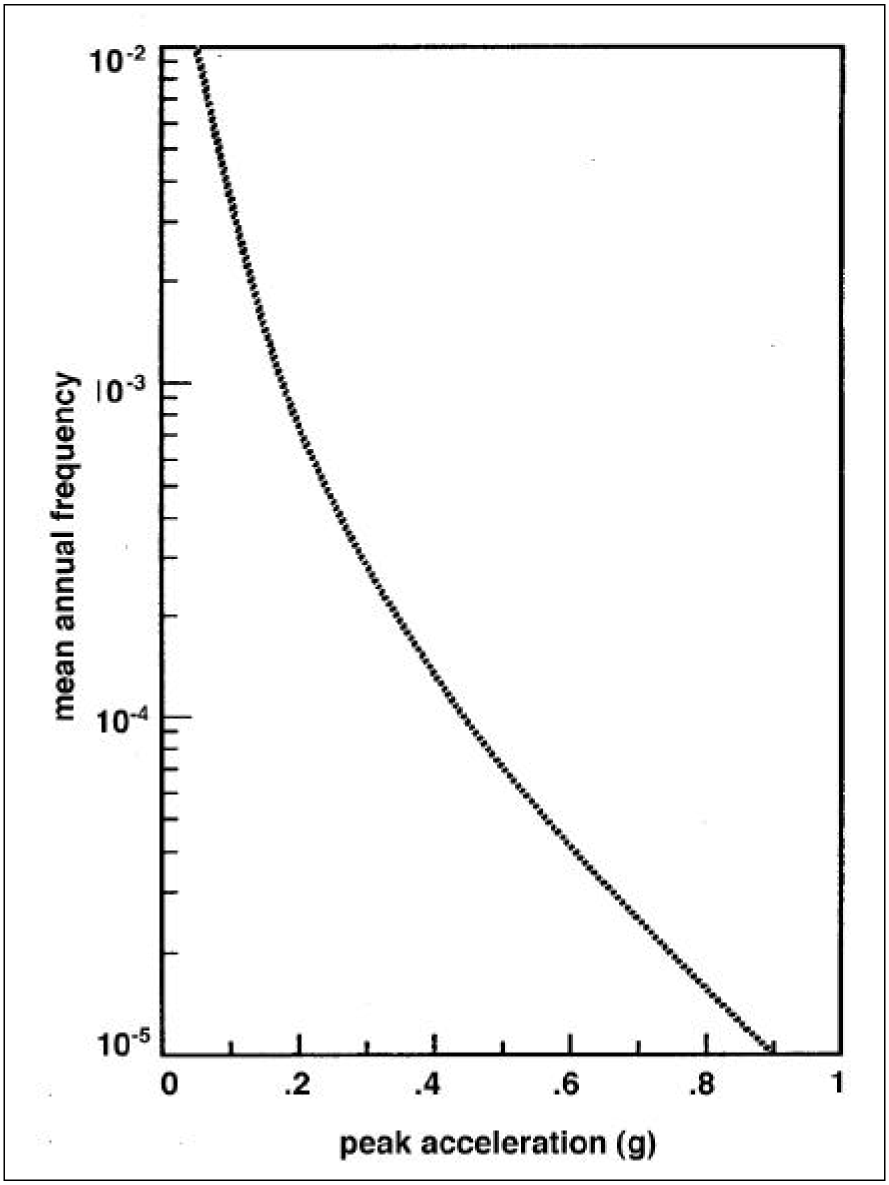


Figure 7. Seismic Hazard Curve at CSB Location

4.6 Cold Vacuum Drying Facility

4.6.1 Background

The CVDF is a new facility of the SNF Project, and is under construction in the 100K Area at the Hanford Site. The CVDF is designed to remove free water from SNF taken from the K-West and East fuel storage basins and to vacuum-dry the fuel before it is transferred to the CSB in the 200 East Area. The CVDF is an above-grade structure with steel framing, a steel plate roof, and pre-cast concrete walls. It is estimated to have a design life of five years.

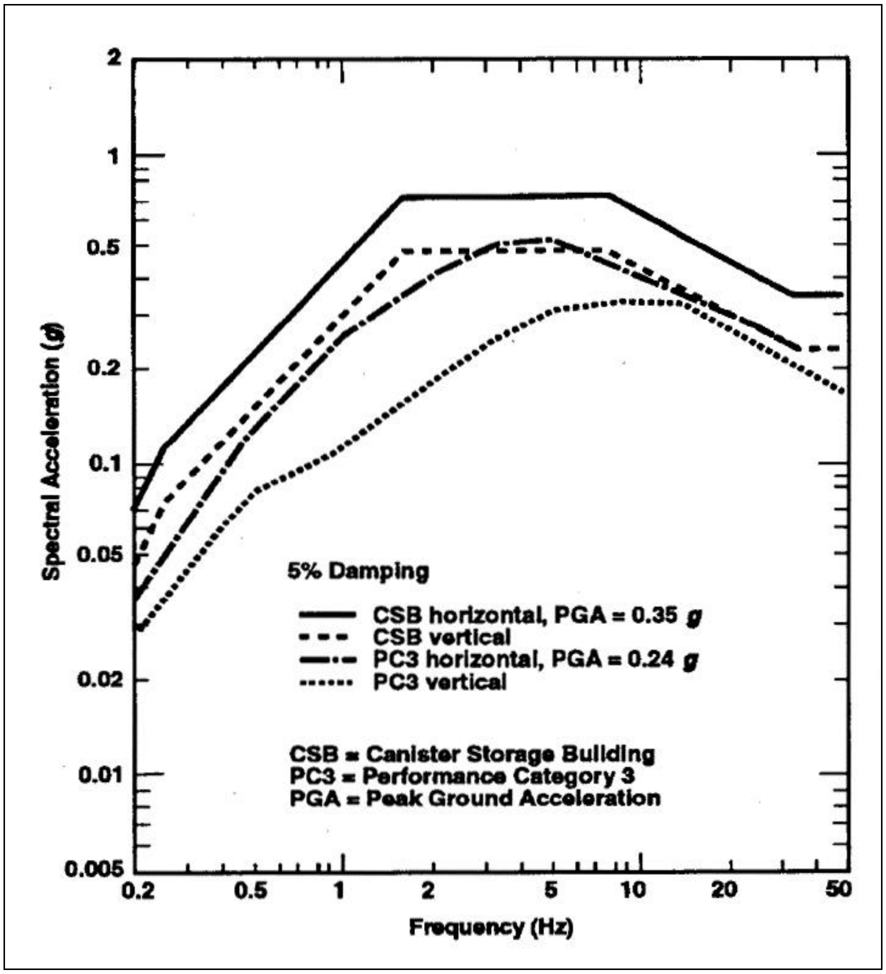


Figure 8. CSB Response Spectra Compared to PC 3 Response Spectra

The design of the CVDF began in 1995-1996, and construction commenced in 1997. Material reviewed to summarize CVDF seismic criteria includes the following:

- *Safety Analysis Report for the Cold Vacuum Drying Facility*, Phase 2, HNF-SD-SNF-SAR-002, Revision 4 (WHC 1996d)

- *Cold Vacuum Drying System, National Phenomena Hazards*, WHC-SD-SNF-DB-010, Revision 1 (WHC 1996b)

- *Spent Nuclear Fuel Project Seismic Design Criteria, NRC Equivalency Evaluation Report*, WHC-SD-SNF-DB-004, Revision 2 (WHC 1996c)

Under the provisions of DOE Order 5480.28 and DOE-STD-1021, the CVDF process building was designated as a PC 3 facility, with a DBE of 0.26g horizontal peak acceleration. DOE-STD-1020 criteria were used for seismic design.

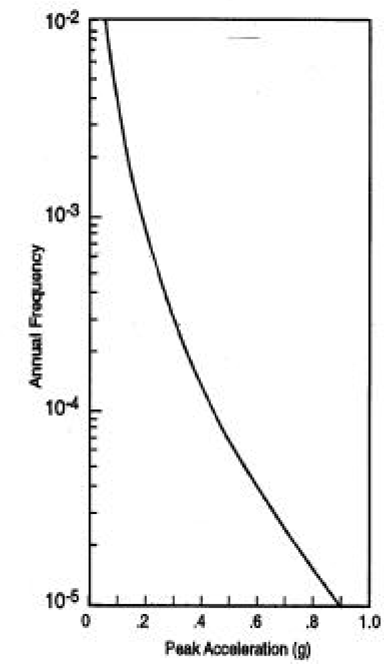


Figure 9. Mean Seismic Hazard Curve at the 100K Area

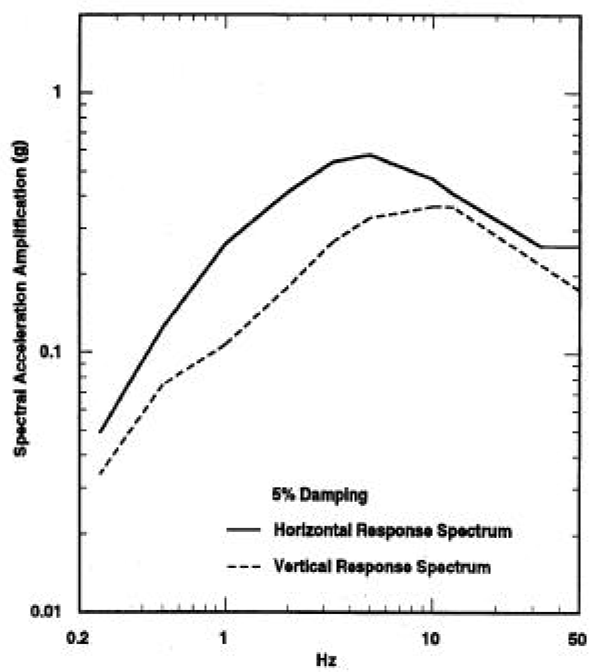


Figure 10. Cold Vacuum Drying Facility Performance Category 3 Response Spectra

4.6.2 Seismic Hazard

Current seismic hazard information for the Hanford Site is obtained from the PSHA for the Hanford Site, prepared by Geomatrix (Geomatrix 1996). For the CVDF (100K Area), the mean hazard curve is given in Figure 9. Based on the mean hazard curve, ground motion levels (spectral acceleration) for different return periods for the 100K Area were computed in the report. Figure 10 shows equal hazard response spectral curves for horizontal (PGA 0.26g) and vertical (PGA 0.18g) ground motion for a 2,000-year return period, which is the target seismic hazard exceedance probability for Performance Category 3, as specified in DOE-STD-1020.

4.6.3 Seismic Design Criteria

Using a graded approach in accordance with DOE-STD-3009, SSCs were categorized as "safety-class," "safety-significant," and "general services." Safety-class SSCs which prevent and/or mitigate public exposures and other non-safety-class SSCs where failure can affect the function of safety-class SSCs were designed to PC 3 criteria if they are required to function during or following an earthquake. Safety-significant SSCs that prevent and/or mitigate co-located worker exposures were designed to PC 3 or PC 2 criteria respectively, depending on whether they have a safety function during or following an earthquake. (The definitions "safety design class" and "safety design significant" proposed and used by BNFL for the TWRS-P project are unrelated to the DOE-STD-3009 definitions "safety-class," "safety significant," and "general services.")

5.0 SEISMIC CRITERIA USED FOR THE DEFENSE WASTE PROCESSING FACILITY AT THE SAVANNAH RIVER SITE, SOUTH CAROLINA

DWPF was designed in the early 1980s to a site-specific 5,000-year return period ground motion, which is between the corresponding PC 3 and PC 4 recurrence intervals seismic criteria guidance in DOE-STD-1020. Seismic design criteria were reviewed by an independent panel of experts.

5.1 Background

The DWPF, located at the Savannah River Site (SRS), is an operating facility that vitrifies high-level liquid radioactive waste stored in underground tanks. Figure 11 shows the location of the Savannah River Site in South Carolina.

The facility is comprised of the Vitrification Building, the Vitrified Waste Storage Building, and Waste Transfer Systems. The Vitrification Building houses a glass melter and necessary equipment for vitrifying high-level radioactive waste. The facility was designed in the 1980s, and began operation in 1996. Material reviewed to summarize the DWPF seismic criteria includes the following:

- 1982 *Update of Seismic Design Criteria (DuPont 1982)*
- 1987 *Structural Specification for Building Code Requirements (DuPont 1987)*
- 1993 *Natural Phenomena Design Assessment of DWPF (Bechtel 1993).*

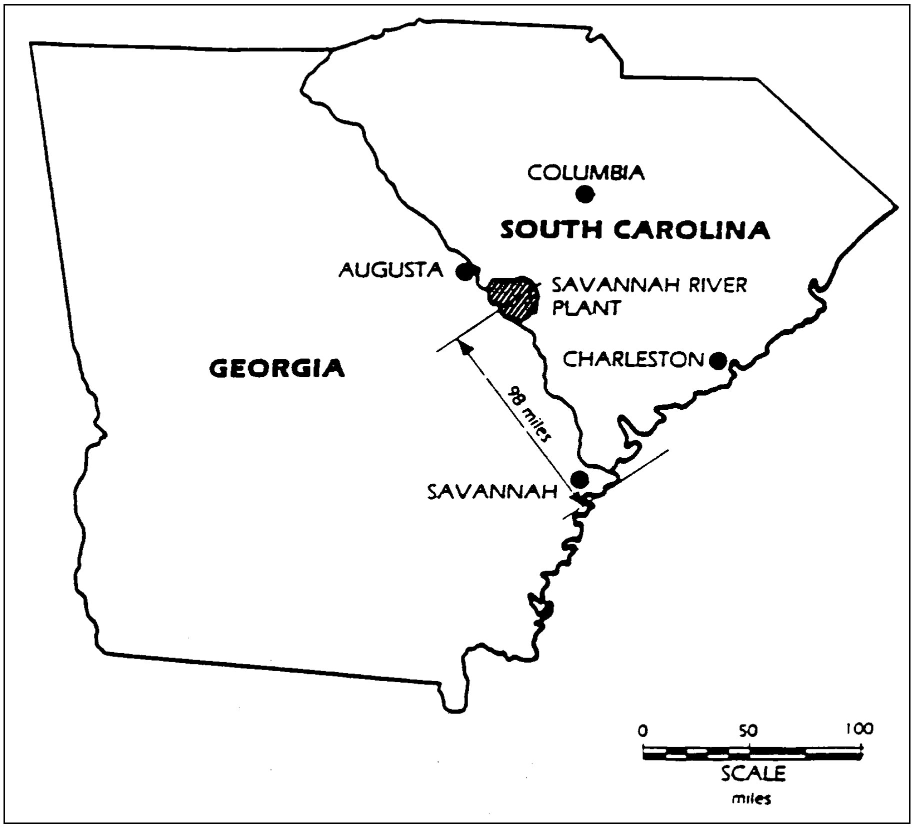


Figure 11. Location of Savannah River Site in South Carolina

5.2 Seismic Hazard

The hazard curve developed by URS/John A. Blume & Associates, Engineers, which forms the basis for DWPF criteria, is shown in Figure 12. The two rates on the figure refer to assumed occurrence rates of the Charleston earthquake.

Response spectra were prepared by performing statistical analyses of data subsets selected from available worldwide strong-motion data. The subsets were selected in order to match, as closely as possible, SRS site conditions and the magnitude and epicentral distance of nearby magnitude-5 and distant magnitude-6.6 design earthquakes. The mean value spectra were calculated separately, then combined and smoothed, producing a spectrum that envelops those derived from the near and far earthquakes. The site-specific response spectra used for designing the DWPF is shown in Figure 13, indicated by the Blume (0.2g) curve. The DOE (0.19g) curve represents the spectra generated using UCRL-15910 recommendations in conjunction with UCRL-53582, Rev. 1 (Coats and Murray 1984).

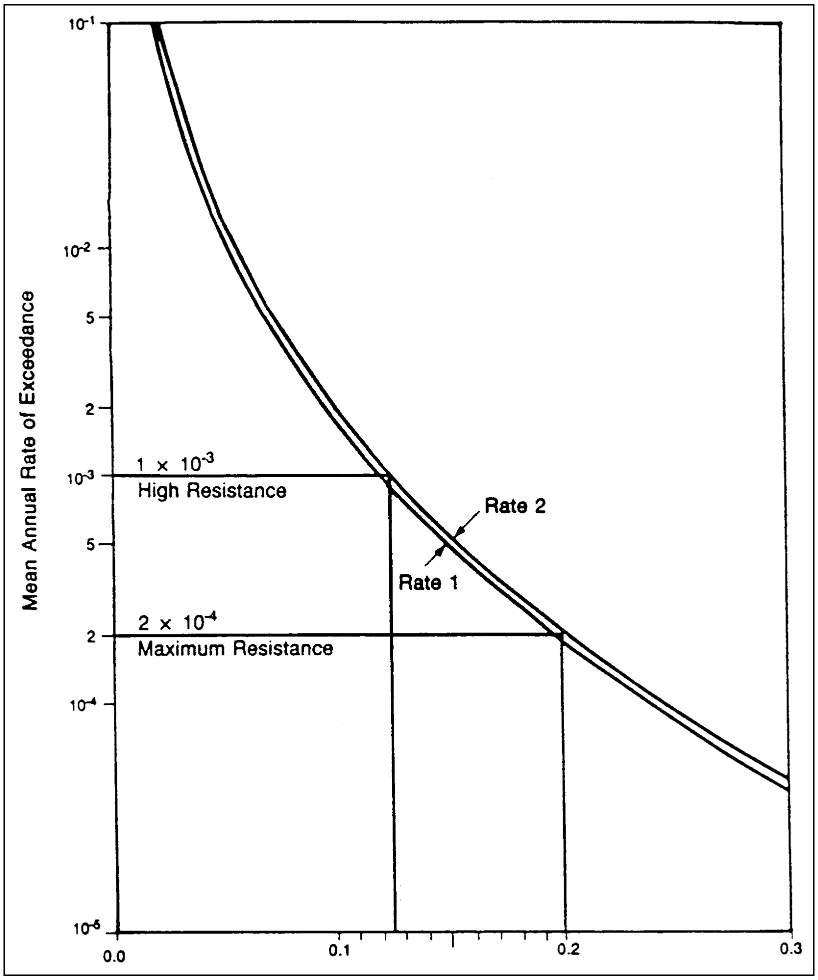


Figure 12. Seismic Hazard Curve Used for Design of DWPF

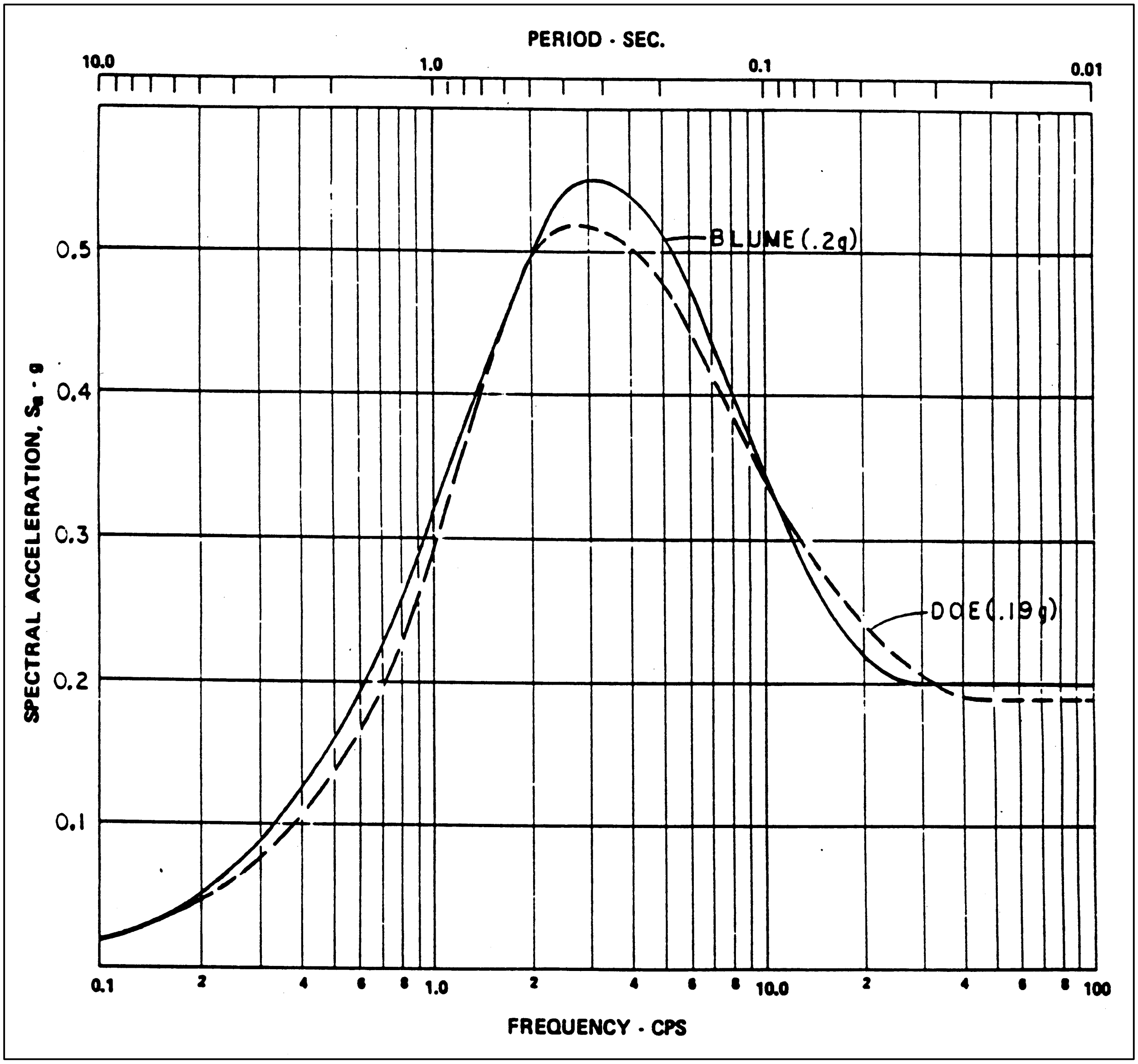


Figure 13. Response Spectra Used For Design of DWPF (5% Critical Damping)

5.3 Seismic Design Criteria

DWPF was designed to reflect the intent of DOE Order 6430.1. The implementation of these design criteria at SRS is contained in Site Specification No. 7096. DWPF was designed before DOE NPH Policy was established in DOE Order 5480.28.

DWPF seismic design criteria were developed by URS/John A. Blume & Associates, based on site-specific studies. These criteria were reviewed and approved by an independent panel of experts in seismology, geology, soils engineering, and earthquake engineering. Table 10 summarizes the Blume seismic criteria for DWPF.

Table 10. Summary of Blume Seismic Design Criteria for DWPF

Type of Analysis	Dynamic
Controlling earthquake	Charleston
Site MMI	VII
Intensity-acceleration relationship	Murphy and O'Brien
PGA	0.20 g (DBE)
Return period (annual probability of exceedance, $2x10^{-4}$)	5,000 years
Response Spectra	Blume Site-Specific
Allowable damping	NRC Reg. Guide 1.61
Floor response spectra	NRC method
Soil-structure interaction (SSI)	NRC method

Three levels of earthquake were defined by DuPont, the DWPF facility operator at the time of design, and were used to design the DWPF SSCs tabulated in Table 11. These requirements were based on DuPont's engineering judgment and their extensive experience in operating nuclear processing facilities at SRS.

Table 11. Earthquake Definitions for DWPF

DBE	The DBE is the most severe seismic event considered credible at the SRS, and represents the design basis seismic accident for safety analysis purposes. Following a DBE, the health and safety of the public must be protected, but there is no requirement that the DWPF be capable of resuming operation.
Investment Protection Earthquake (IPE)	The IPE has a lower *g* level and a higher probability of occurrence than the DBE. Following an earthquake at the IPE level, damage to equipment would be expected, and operations would be shut down; however, no damage that would prevent the DWPF from being restarted (following repairs, cleanup, etc.) should occur as a result of an IPE.
UBC –1979	The 1979 UBC earthquake provisions are used for all structures, systems, and components not designed to meet DBE and/or IPE requirements.

The SSCs at DWPF are classified into three design categories, as described below.

Category I (Maximum Resistance) – These SSCs which, by virtue of client direction or the safety assessment process, must withstand the effects of both DBE and design basis tornado loads (DuPont 1987).

Category II (Intermediate Resistance) – This category is comprised of those SSCs which are not in Category I, but whose failure could endanger a Category I SSC. Adequate structural separation is provided to ensure that either a detrimental interaction with a Category I structure does not occur, or that an analysis is performed to show that the failure of a Category II structure will not prevent the Category I structure from performing its safety function.

Category III (Standard Resistance) – Any SSC not classified as Category I or II belongs in this category, and is designed in accordance with the provisions of conventional building codes (1979 UBC).

The following seismic criteria are used in the design of SSCs for the three levels of earthquakes listed in Table 11.

DBE - For facilities that must be designed to withstand this level of earthquake, seismic loads are based on a maximum ground acceleration of 0.2g in the horizontal direction, and 0.13g (0.67 x 0.2g) in the vertical direction.

Seismic design of DBE-resistant SSCs is based on elastic dynamic analysis. Time histories, response spectra, and SSIs were considered, as appropriate, in the design. The DBE was determined from the site-specific studies performed by URS/John A. Blume & Associates. The PGA of 0.2g was used for the DBE, along with the damping values recommended in NRC Regulatory Guide 1.61. The total structural response is obtained by combining the structural response in two horizontal directions and one vertical direction.

IPE - For facilities required to be designed to withstand this earthquake, the seismic loads are based on a maximum ground acceleration of 0.1g in the horizontal direction, and 0.07g (0.67 x 0.1g) in the vertical direction.

UBC 1979 - All facilities not designed for DBE or IPE are designed in accordance with the provisions of the 1979 UBC.

During a reevaluation in 1993, usage categories were assigned to each SSC before the applicable requirements of DOE Order 6430.1A were applied. A hazard assessment was performed for the DWPF by the Savannah River Technical Center. The hazard assessment divided the DWPF into 17 different segments to evaluate their effectiveness against natural phenomena hazards. The results are summarized in Table 12.

Table 12. Summary of DWPF Hazard Assessment Results

Segment Number	Segment Description	Use Category
1	Vitrification Building	High
2	Sand Filter	Low
3	Fan House	Low
4	Glass Waste Storage – Vault	Moderate
5	Glass Waste Storage – Operations	Low
6	Glass Waste Storage – Office	General Use
7	Service Building	General Use
8	Administration Building	General Use
9	Exhaust Stack	Low
10	Auxiliary Pump Pit	High
11	Low Point Pump Pit	High
12	Failed Equipment Vault – 1	Low
13	Failed Equipment Vault – 2	Low
14	Organic Waste Storage Tank	Moderate
15	Waste Treatment	High
16	Bulk Storage	General Use
17	Cold Chemical Feed Storage	High

Based on the results of the evaluation, the Vitrification Building and related operations were categorized as High Hazard facilities. Other parts of the facility were categorized as General Use, Low, and Moderate Hazard. Design of the High Hazard facilities to the 5,000-year earthquake was consistent with DOE NPH policy at the time of reassessment.

6.0 SEISMIC CRITERIA USED FOR THE WEST VALLEY DEMONSTRATION PROJECT AT THE WESTERN NEW YORK NUCLEAR SERVICE CENTER, WEST VALLEY, NEW YORK

WVDP meets seismic design criteria for a PC 3 facility, but used the NRC Regulatory Guide 1.60 spectra and 1.61 damping values. DOE and NRC worked together in the seismic review of WVDP.

6.1 Background

The WVDP is located at the Western New York Nuclear Service Center (WNYNSC), owned by the state of New York. This was the site of the first commercial nuclear reprocessing operation in the United States. Nuclear Fuel Service, Inc. (NFS) operated the plant. WVDP is located near West Valley, New York, on approximately 150 acres within the 3,345-acre WNYNSC, approximately 35 miles south of Buffalo, New York (see Figure 14). Project facilities include the former NFS Reprocessing Plant and related facilities, and several new facilities constructed for the WVDP.

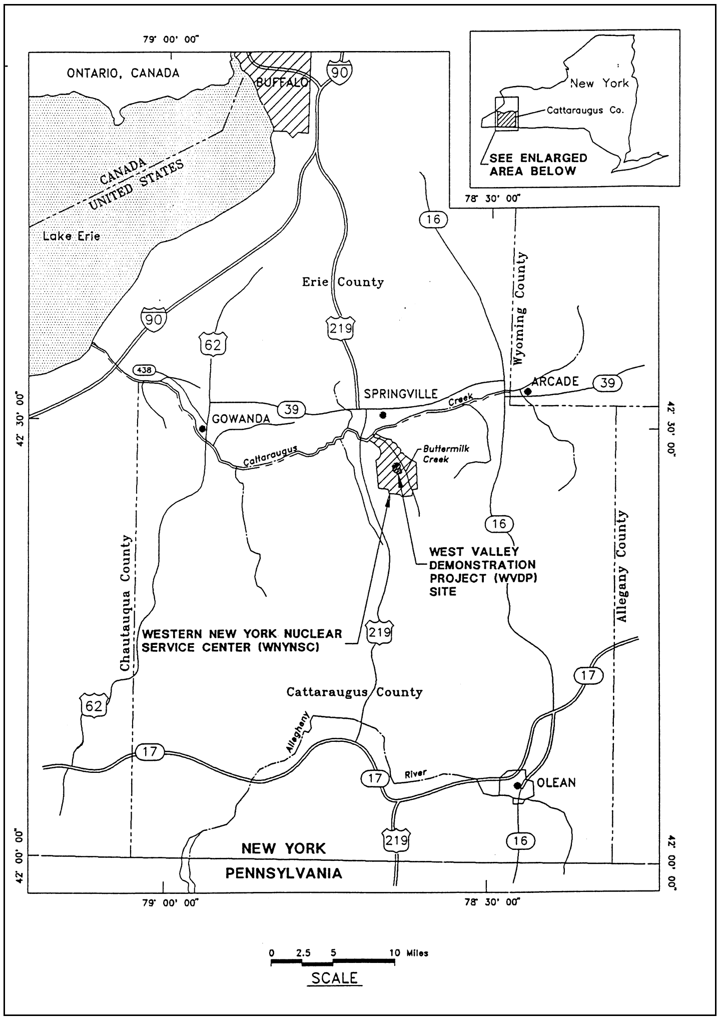


Figure 14. Location of the Western New York Nuclear Service Center

Between 1966 and 1972, NFS, under NRC license, operated a spent fuel reprocessing plant at the WNYNSC. During this period, the plant reprocessed light water reactor spent fuel. A limited quantity of thorium-bearing fuel was also reprocessed. The reprocessing plant ceased operations in 1972. During the six-year period of reprocessing operations, approximately 2.2 million liters of high-level waste (HLW) were produced.

In 1982, as a result of the West Valley Act of 1980, DOE assumed control of the site from NFS. Since that time, DOE and its contractor, West Valley Nuclear Services (WVNS), have operated the facility. To date, WVDP has completed several pretreatment activities while maintaining the tank farm and existing facilities.

Material reviewed to evaluate WVDP includes the following:

- 1995 *Report on Evaluation of Ground Motion Hazard (Dames & Moore 1995),*
- 1995 *DOE Safety Evaluation Report Supplement (DOE 1995),*

- 1995 *NRC Safety Evaluation Report (NRC 1995),*
- 1995 *Excerpts from the Safety Analysis Report (WVNS 1995).*

6.2 Seismic Hazard

In 1983, DOE accepted a DBE for the site based on an original study conducted by Dames & Moore. This resulted in the DBE parameters, PGA=0.10g Horizontal, 0.067g Vertical with RG 1.60 Response Spectra. The seismic hazard curves from the 1983 Dames & Moore study are shown in Figure 15.

In 1995, the original 1983 study was reevaluated. Ground motion estimates were made based on a 1992 Dames & Moore study, more recent interpretations of the data, and improvements to seismic hazard assessment methodology, as documented in studies by the Electric Power Research Institute (EPRI) and LLNL. Data for the Ginna commercial nuclear power plant, located 145 km northeast of WVDP and considered to have similar site conditions, were also used in the seismic hazard reevaluation. This led to development of 0.079g for the PGA.

Previous safety analyses of WVDP had resulted in the facility being categorized as a Moderate Hazard, or PC 3 facility. Since both PC 2 and PC 3 values were less than the minimum PGA of 0.10g suggested by NRC, and since 0.10g was previously established and accepted as the DBE for the facility, no additional seismic hazard reassessment work was undertaken.

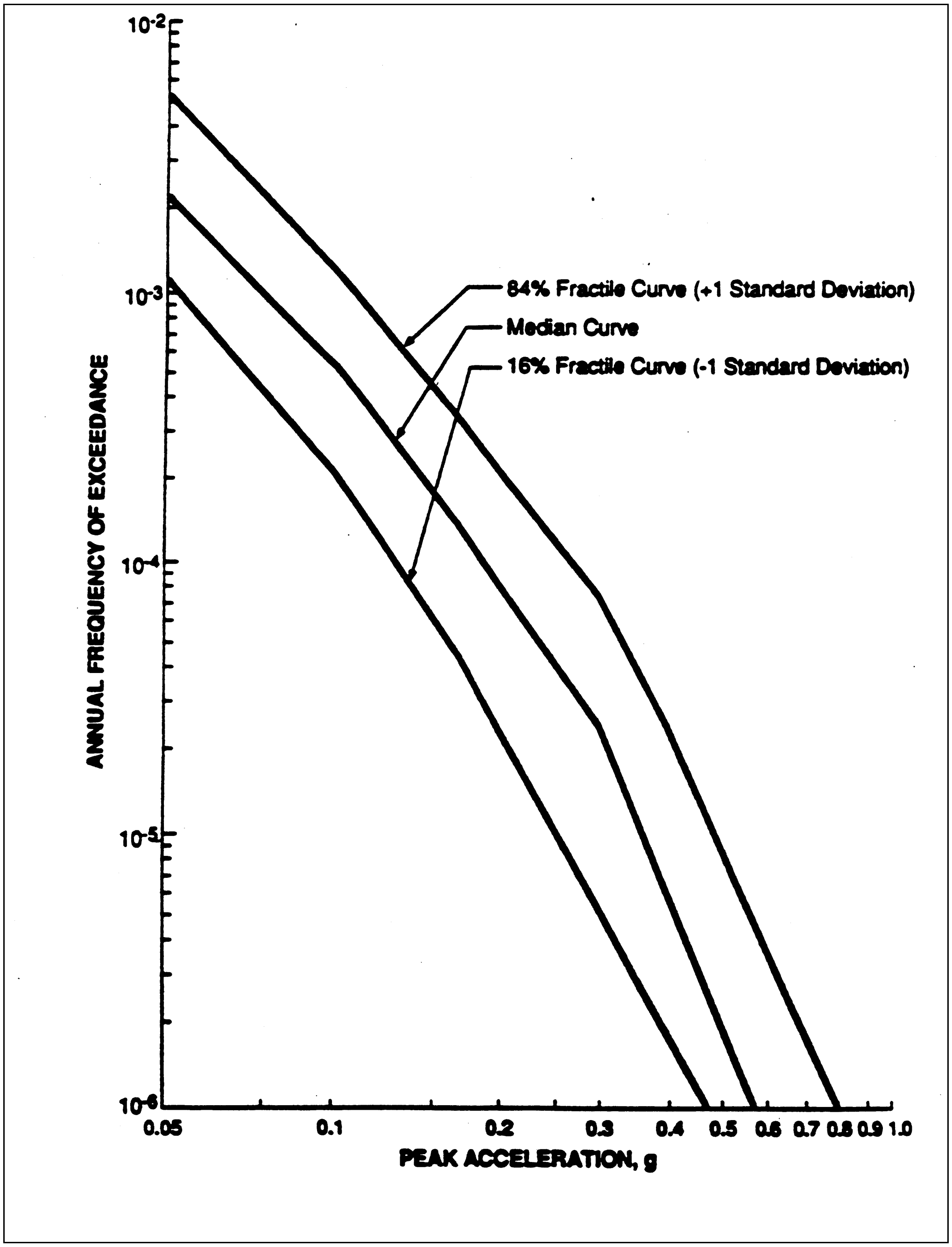


Figure 15. Seismic Hazard Curves From Dames & Moore 1983 Study

6.3 Seismic Design Criteria

Appropriate industry standards were used in designing various components and structures for each safety class and quality level. Components and systems were evaluated against these design concepts and standards, and were consistently found to be adequate.

The design approach for the Vitrification Facility (VF) reflected good engineering practice, and was based on methodology historically used for facilities with similar or greater hazards. The design philosophy for the VF emphasizes multiple barriers of confinement to prevent potential radiological releases. The outermost level of confinement was provided by passive confinement structures and components whose continued function under all but incredible conditions was assured by design. The population of SSCs considered for seismic loading in the SAR include those important to active and passive confinement. The major structural elements of the confinement barriers, including the roof, walls, and mat, have margins of safety greater than 3.5 times the DBE.

Margins of safety against the DBE for other SSCs were considered acceptable, and were re-evaluated for certain important structures with relatively low margins from previous analyses. In particular, margins for the process tanks and tank support frame were re-evaluated to be greater than 2.0 times the DBE and 2.2 times the DBE, respectively (previous values were greater than 1.7 times the DBE and 1.4 times the DBE, respectively). Margins of safety indicate that no component or structure analyzed will fail at the DBE, and only four have margins less than twice the DBE.

Both DOE and NRC prepared SERs on the SAR submitted by WVNS. NRC's SER emphasized safety of radiological operations and chemical hazards that could cause radiological consequences. DOE's SER emphasized safety of non-radiological chemical processing hazards. Both SERs formed the basis for approval of the SAR.

7.0 SEISMIC CRITERIA PROPOSED FOR THE TANK WASTE REMEDIATION SYSTEM-PRIVATIZATION PROJECT, HANFORD SITE, WASHINGTON

Proposed seismic criteria for the TWRS-P Important to Safety/Safety Design Class SSCs with NPH safety function use a 2,000-year return period ground motion, and generally follow DOE-STD-1020 seismic guidance, but use lower damping values, limit response to elastic behavior, and provide ductile detailing.

7.1 Background

The TWRS-P Project is sponsored by DOE to treat and immobilize wastes from the Hanford Site underground waste storage tanks into a glass product encased in stainless steel canisters for long-term storage. BNFL is the Privatization Contractor for the initial phase of the project. The proposed BNFL TWRS-P complex consists of a radioactive waste treatment building and several support structures. The DOE regulatory approach for TWRS-P activities requires that the contractor take an active role in identifying and recommending the standards and requirements that will be used to achieve adequate safety for its specific activities. These standards and requirements, and an initial safety assessment of the proposed BNFL facility, are contained in the following documents, which were used to summarize the seismic design criteria proposed and approved for the TWRS-P project.

- *TWRS-P Project Safety Requirements Document,* Volume II, BNFL-5193-SRD-01, Rev. 1, June 10, 1998 (BNFL 1998a)

- *TWRS-P Project Initial Safety Analysis Report*, BNFL-5193-ISAR-01, Rev. 0, January 12, 1998 (BNFL 1998).

Note that the TWRS-P Project is in a very early stage of execution, and the approved criteria are subject to revision as the project evolves.

7.2 Seismic Hazard

Both the Safety Requirements Document (SRD) and the Initial Safety Analysis Report (ISAR) have utilized seismic hazard information given in the PSHA for the Hanford Site, prepared by Geomatrix (Geomatrix 1996). For the proposed TWRS-P Project site (200 East Area), the mean seismic hazard curve and the 2,000-year return period equal hazard response spectral curves are shown in Figures 16 and 17, respectively.

7.3 Seismic Design Criteria

The TWRS-P Project has categorized SSCs into two groups for NPH design. The groups are SSCs Important to Safety and SSCs without NPH Safety Function. Proposed seismic design criteria for each group are summarized below.

7.3.1 SSCs Important to Safety

SSCs designated as Important to Safety (i.e., Safety Design Class and Safety Design Significant with an NPH safety function) follow safety criterion 4.1-3 (BNFL 1998a) and shall be designed to withstand the effect of NPH events such as earthquakes, wind, and floods without losing the capability to perform specific safety functions required as the result of NPH events. This includes both the front-line and support systems that must function for an NPH event, such that public or worker exposure standards are not exceeded.

SSCs designated as Safety Design Class that are required to perform a safety function as a result of a given earthquake shall be designed to withstand the loadings of the NPH as provided in Table 13. No credit will be taken for inelastic behavior.

Although the continued function of an SSC designated as Safety Design Significant is not required for an NPH event, its failure as a result of an NPH event could reduce the functioning of a Safety Design Class SSC such that exposure standards might be exceeded. Therefore, these SSCs shall be designed to withstand earthquake loadings, as provided in Table 13. For these SSCs, however, credit may be taken for inelastic energy absorption, as specified in Table 2-4 of DOE-STD-1020.

Table 13. Natural Phenomena Design Loads for Important to Safety SSCs with NPH Safety Functions

Hazard	Load	Applicable document
Seismic	Equal-hazards response spectra PGA 0.24 g horizontal, @ 33 Hz. PGA 0.16 g vertical, @ 50 Hz. See Figures 16 and 17	DOE-STD-1020

7.3.2 SSCs without NPH Safety Function

SSCs without NPH safety function follow Safety Criterion 4.1-4 (BNFL 1998a) and shall be designed to withstand the effects of NPH such as earthquakes, wind, and floods. SSCs included under this criterion are:

- SSCs Important to Safety (either Safety Design Class or Safety Design Significant) that do not have an NPH safety function
- SSCs not Important to Safety that have significant inventories of radioactive or hazardous materials, but in amounts less than those that might lead to an Important to Safety designation.

SSCs included under this criterion shall be designed to withstand NPH loadings as provided in Table 14.

Table 14. Natural Phenomena Design Loads for SSCs Without NPH Safety Functions

Hazard	Load	Applicable document
Seismic	Uniform Building Code, with the following modifications ZC = 0.55 Importance Factor I = 1.25 R_w per Table 2-2 of DOE-STD-1020	DOE-STD-1020

The Importance Factor of 1.25 is used in the UBC for design of essential facilities such as firehouses and hospitals. Conventional facilities are designed with an Importance Factor of 1.0. Also, the UBC allows the seismic loads to be reduced by the factor R_w, which ranges from 5 to 12, depending on the structural system. The above formulation is based on UBC 1994, has been modified in the current UBC code (1997).

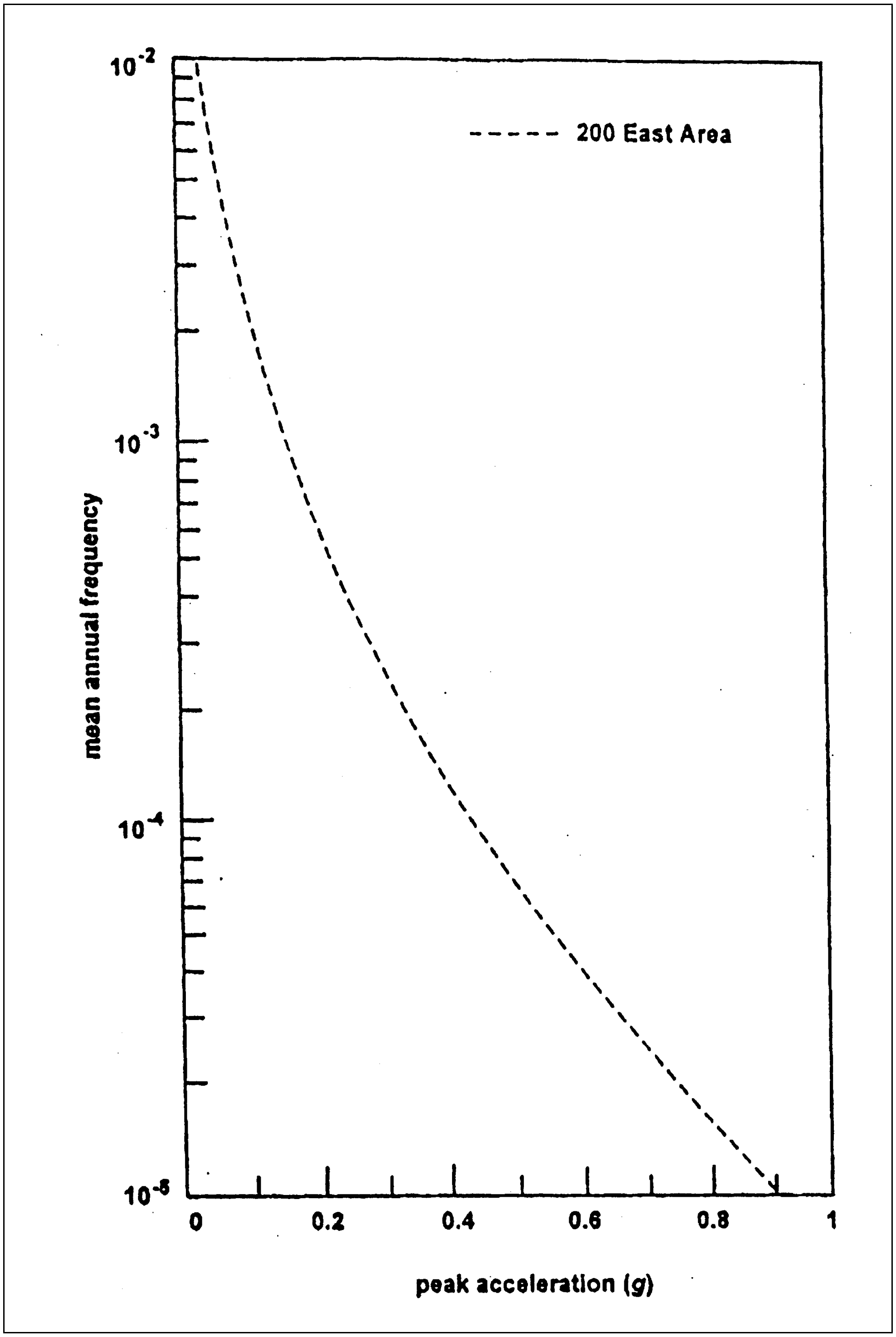


Figure 16. Mean Seismic Hazard Curve for the 200 East Area

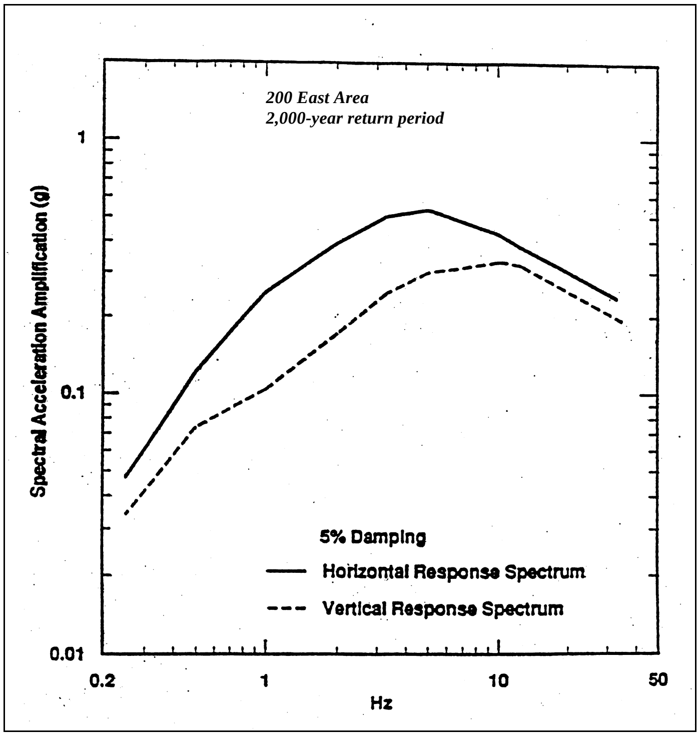


Figure 17. Spectral Acceleration for Important to Safety SSCs with NPH Safety Functions

8.0 SUMMARY

This report documents the evolution of seismic design criteria at Hanford from its beginning in the 1940s to the present day. Seismic design criteria at Hanford have changed with time as more information on the potential seismic sources became available, as the methodology for estimating seismic hazards has improved, and as seismic design requirements used for commercial and DOE nuclear facilities has developed. The Hanford Plant Standard had been revised periodically to reflect the latest information on site seismic hazards, and incorporates the relevant provisions of DOE NPH Policy.

The DOE NPH Policy was established in 1993 with the issuing of the NPH Order to apply a graded approach to meet Performance Goals (PGs) ranging from 10^{-3}/year to 10^{-5}/year. For each Performance Category, hazard exceedance frequencies were determined from the PGs and from the conservatism in the design criteria. PGs have remained unchanged during the period 1985–1996 when the NPH Policy was evolving; however, the earthquake return periods for PC 3 and PC 4 facilities were doubled as more probabilistic seismic hazard information became available (for Moderate Hazard 1,000-year increased to 2,000-year for PC 3 and High Hazard 5,000-year increased to 10,000-year for PC 4). Prior to the establishment of the DOE NPH Policy, DOE applied more conservative criteria to non-reactor nuclear facilities. This can be seen in the seismic design criteria used for DWPF and the HWVP-CSB. The current DOE NPH Policy provides a systematic framework for categorizing these facilities as PC 3 and for their seismic design.

8.1 Hanford

Over the past 50 years, both DOE and commercial reactor facilities at the Hanford Site have been designed using seismic criteria with a horizontal peak ground acceleration of 0.25g. The HWVP CSB used 0.35g, which was selected conservatively due to uncertainty regarding the prospective DOE NPH Policy seismic criteria. For cost and scheduling reasons, these criteria were retained as the HWVP CSB became part of the SNF Project. Current Hanford criteria recommend a PGA of 0.26g on the Hanford Site for PC 3 SSCs.

8.2 DWPF

The DWPF was designed to a peak ground acceleration of 0.20g, which corresponds to a 5,000-year earthquake and a site-specific response spectra. Design of DWPF took place prior to issuance of DOE NPH guidance. A reassessment of the facility in 1993 indicated that parts of the facility (mostly building structures) would be placed in the high-hazard category. The facility was seismically evaluated and met the 1993 DOE seismic criteria, which allowed a 5,000-year earthquake for high-hazard facilities. There was no NRC involvement in the design or review of DWPF.

8.3 WVDP

WVDP was originated by a Congressional Act in 1980. DOE and NRC both had specific roles in carrying out the project. DOE and NRC issued a Memorandum of Understanding for work on the project.

Ground motion estimates for the West Valley Site were less than the NRC-recommended minimum value, so the minimum NRC horizontal PGA value of 0.1g was used in its design. NRC Regulatory Guides 1.60, *Response Spectra,* and 1.61, *Damping Values*, were used in the seismic design, which followed industry practice. The SAR and SERs prepared by NRC and DOE categorized the facility as PC 3, and indicated that the design typically had safety margins greater than twice the DBE levels.

8.4 TWRS-P

The proposed TWRS-P seismic design criteria generally adopt DOE-STD-1020, and have used a horizontal PGA of 0.24g and the equal hazard spectra specified in the 1996 Geomatrix PSHA (Geomatrix 1996) for the 200 East Area. The PSHA, however, shows a slightly higher PGA of 0.26g for the adjacent 200 West Area. The response spectra shapes are almost identical. The current 1997 Hanford Plant Standard (Conrads 1997) bounded these two values and recommends use of a 0.26g PGA design earthquake for the 200 East Area. The current ability to predict ground motion and design structures cannot distinguish between these PGA levels.

NEHRP provisions require that, for hazardous facilities, the design basis earthquake will have a return period of approximately 2,500 years. NRC staff, in an issue paper (NRC, 1998) on seismic events for TWRS-P, have preliminarily endorsed this NEHRP provision as the minimum baseline criterion which will have to be validated via appropriate safety analyses to demonstrate that this level of seismic protection is adequate to comply with the mandated accident dose standards for all credible accidents. As a point of comparison, the mean PGA for the 200 East Area, using USGS hazard maps and corrected for site conditions, is 0.27g for a 2,500-year return period. The corresponding PGA for a 2,000-year return period is 0.23g, by interpolation. Thus, the mean PGA estimates for the 200 East Area, where TWRS-P will be located, range from 0.23g to 0.26g for a 2,000-year return period.

9.0 REFERENCES

Bandyopadhyay, K. et al., 1995, *Seismic Design and Evaluation Guidelines for the Department of Energy High-Level Waste Storage Tanks and Appurtenances*, BNL 52361, October.

Bechtel National Inc., 1993, *Defense Waste Processing Facility, Savannah River Site - S Area Natural Phenomena Design Assessment*, February.

Blume, J. A., 1971, *Seismic Evaluations and Development of Ground Acceleration and Response Spectra for FFTF*, February.

BNFL, 1998, *TWRS-P Project Initial Safety Analysis Report*, British Nuclear Fuels Limited, BNFL-5193-ISAR-01, Rev. 0, January.

BNFL, 1998a, *TWRS-P Project Safety Requirements Document*, Volume II, British Nuclear Fuels Limited, BNFL-5193-SRD-01, Rev. 1, June.

Coats, D. W., and R. C. Murray, 1984, *Natural Phenomena Hazards Modeling Project: Seismic Hazard Models for Department of Energy Sites*, Lawrence Livermore National Laboratory, UCRL-53582, Rev 1, November.

Conrads T. J. and L. K. Severud, 1988, Memo to H. Heacock, *Background on Hanford Reservation Safe Shutdown Earthquake*, Westinghouse Hanford Company, May 18.

Conrads, T. J., 1990, *Hanford Site Seismic Technology*, Westinghouse Hanford Company, Viewgraphs dated June.

Conrads, T. J., 1994, Memo to R. C. Fritz, *Seismic Response Spectra Anchors-W236A*, Westinghouse Hanford Company, December 7.

Conrads, T. J., 1997, *Engineering Design and Evaluation*, HNF-PRO-97, Rev. 0, August.

Coppersmith, et al., 1981, *Seismic Exposure for the WNP-2 and WNP-1/4 Site*, Appendix 2.5K, Amendment 18, Final Safety Analysis Report, WNP-2, Washington Public Power Supply System, Richland, Washington.

Dames & Moore, 1995, *Evaluation of Ground Motion Hazard at the West Valley Demonstration Project Site*, West Valley, New York, for West Valley Nuclear Service Company, Inc., January 27.

DOE, 1983, DOE Order 6430.1, *General Design Criteria*, U. S. Department of Energy, December.

DOE, 1993, DOE Order 5480.28, *Natural Phenomena Hazards Mitigation*, U.S. Department of Energy, Washington D.C., January 15.

DOE, 1994, DOE-STD-3009, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Safety Analysis Reports*, U.S. Department of Energy, July.

DOE, 1995, *Safety Evaluation Report for Vitrification Operation & High-Level Waste Interim Storage*, WVAO-SER-003, Rev 0, Draft A, June 15.

DOE, 1995a, DOE Order 420.1, *Facility Safety*, U.S. Department of Energy, Washington D.C., October.

DOE, 1995b, DOE Guide 420.1, *Guidance for the Mitigation of Natural Phenomena Hazards for DOE Nuclear Facilities and Non-Nuclear Facilities*, U.S. Department of Energy, Washington D.C., November.

DOE, 1996, DOE Standard DOE-STD-1020, *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities*, U.S. Department of Energy, Washington D.C., January 1.

DOE, 1996a, DOE Standard DOE-STD-1021, *Natural Phenomena Hazards Performance Categorization Guidelines for Structures, Systems, and Components*, U.S. Department of Energy, Washington D.C., January.

DOE, 1996b, DOE Standard DOE-STD-1022, *Natural Phenomena Hazards Site Characterization Criteria*, U.S. Department of Energy, Washington D.C., January.

DOE, 1996c, DOE Standard DOE-STD-1023, *Natural Phenomena Hazards Performance Assessment Criteria*, U.S. Department of Energy, Washington D.C., January.

DuPont, 1984, *Update of Seismic Design Criteria for the Savannah River Plant – Engineering Design for Maximum Resistance Facilities*, E. I. duPont de Nemours Co., Inc., June.

DuPont, 1987, Site Specification No. 7096, *Structural Specification for Building Code Requirements - All Projects Savannah River Plant*, E.I. duPont de Nemours Co., Inc., Revision 3, January 16.

DuPont, 1982, *Update of Seismic Design Criteria for the Savannah River Plant, An Executive Summary*, E.I. duPont de Nemours Co., Inc., Engineering Department, Wilmington, Delaware, Rev. O, May.

Garvin, L. J., 1997, *Spent Nuclear Fuel Project Seismic Design Criteria – NRC Equivalency Evaluation Report*, WHC-SD-SNF-DB-004, Rev 2A, Fluor Daniel Hanford, Inc., March.

Geomatrix, 1996, *Probabilistic Seismic Hazard Analysis, DOE Hanford Site, Washington*, WHC-SD-W236A-TI-002, Rev. 1A, October.

HPS, 1989, *Hanford Plant Standards Design Criteria*, SDC-4.1.

HPS, 1993, *Hanford Plant Standards Design Criteria*, SDC-4.1, January.

ICBO, 1997, 1997 *Uniform Building Code*, Volume 2 Structural Engineering Design Provisions, International Conference of Building Officials, Whittier, California, April.

Kennedy, R. P. and S. A. Short, 1994, *Basis for Seismic Provisions of DOE-STD-1020*, Lawrence Livermore National Laboratory, UCRL-CR-111478, April.

Kennedy, R. P., et al., 1990, *Design and Evaluation Guidelines for Department of Energy Facilities Subjected to Natural Phenomena Hazards*, Lawrence Livermore National Laboratory, UCRL-15910, June.

NEHRP, 1997, *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures*, 1997 Edition, Building Seismic Safety Council, Washington, DC.

Newmark, N. M. and W. J. Hall, 1978, *Development of Criteria for Seismic Review of Selected Nuclear Power Plants*, Nuclear Regulatory Commission Report NUREG/CR-0098, May.

NRC, 1973, Regulatory Guide 1.61, *Damping Values for Seismic Analysis for Nuclear Power Plants*, U.S. Nuclear Regulatory Commission, October.

NRC, 1974, Regulatory Guide 1.60, *Design Response Spectra for Seismic Design of Nuclear Power Plants*, U.S. Nuclear Regulatory Commission, Regulatory Guide 1.60.

NRC, 1994, Sobel, P., *Revised Livermore Seismic Hazard Estimates for Sixty-nine Nuclear Power Plant Sites East of the Rocky Mountains*, NUREG-1488, Washington, D.C., April.

NRC, 1995, *Safety Evaluation Report on the West Valley Demonstration Project Vitrification Process and High-Level Waste Interim Storage*, A Review of WVNS-SAR-003-Rev 2, Draft D, U.S. Nuclear Regulatory Commission, May.

NRC, 1997, Regulatory Guide 1.165, *Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion*, U.S. Nuclear Regulatory Commission, Regulatory Guide 1.165, March.

NRC, 1998, Issue Paper – *Seismic Events for TWRS*, Letter from R. C. Pierson, U.S. NRC, to D. C. Gibbs, U.S. DOE, dated June 29 (w/o attachment Consideration of Seismic Events for Integrated Safety Analysis of the Hanford Tank Waste Remediation System).

TERA, 1981, *Seismic Hazard Analysis for the Hanford Reservation*, Richland, Washington, TERA Corporation, Revised 1981.

WHC, 1990, *Summary Status on the Seismic Evaluations of Hanford Site Radioactive Waste Storage Tanks*, Westinghouse Hanford Company, WHC-EP-0373, September.

WHC, 1992, *Hanford Waste Vitrification Plant Functional Design Criteria*, Westinghouse Hanford Company, WHC-SD-HWV-FDC-001, September 15.

WHC 1992a, *Hanford Waste Vitrification Plant Preliminary Safety Analysis Report* (HWVP PSAR), Westinghouse Hanford Company, WHC-SD-HWV-PSAR-001, Rev. 0.

WHC, 1993, *Hanford Plant Standards Design Criteria*, Standard ARCH-CIVIL Design Criteria for Design Loads for Facilities, Westinghouse Hanford Company, SDC 4.1, Revision 12, December 16.

WHC, 1996, *Canister Storage Building Safety Analysis Report Phase 3*, Westinghouse Hanford Company, WHC-SD-SNF-RPT-004.

WHC, 1996a, *Canister Storage Building Natural Phenomena Hazards*, Westinghouse Hanford Company, WHC-SD-SNF-DB-009, Revision 4, September.

WHC, 1996b, *Cold Vacuum Drying System, Natural Phenomena Hazards*, Revision 1, Westinghouse Hanford Company, WHC-SD-SNF-DB-010.

WHC, 1996c, *Spent Nuclear Fuel Project Seismic Design Criteria NRC Equivalency Evaluation Report*, WHC-SD-SNF, DB-004, Revision 2A.

WHC, 1996d, *Safety Analysis Report for the Cold Vacuum Drying Facility*, Phase 2, HNF-SD-SNF-SAR-002, Revision 4.

Woodward-Clyde Consultants, 1989, *Evaluation of Seismic Hazard for Nonreactor Facilities, Hanford Reservation, Hanford, Washington*, WHC-MR-0023.

WPPSS, 1986, *Geology, Seismology, and Geotechnical Engineering*, WNP-2 FSAR, Amendment 5, Washington Public Power Supply System, May.

WPPSS, 1994, *Seismic Design*, WNP-2 FSAR, Amendment 6, Washington Public Power Supply System, November.

WVNS 1995, *Excerpts from Safety Analysis Report for Vitrification System Operations and High-Level Waste Interim Storage*, WVNS-SAR-003, Rev, West Valley, NY, West Valley Nuclear Services Company, Inc.

YMP, 1997, *Preclosure Seismic Design Methodology for a Geologic Repository at Yucca Mountain*, Topical Report YMP/TR-003-NP, Revision 2, August.

10.0 ACKNOWLEDGMENT

This report was prepared for the RU by Dr. Robert C. Murray, Lawrence Livermore National Laboratory and Dr. Subir K. Sen, EH-34.

T. J. Conrads, Numatech-Hanford Corporation provided information on the evolution of the seismic design criteria at the Hanford Site. Mr. Conrads has been involved with the Hanford Site seismic design for over 23 years. He also reviewed and commented on the draft report.

B. Gutierrez, DOE/Savannah River Office and T. J. Jackson, DOE/West Valley Demonstration Project, provided pertinent information on the seismic design of DWPF and WVDP facilities and also reviewed the respective sections of the draft report.

APPENDIX A. LIST OF ACRONYMS

Acronym	Definition
ACRS	Advisory Committee on Reactor Safety (NRC Oversight)
AEC	Atomic Energy Commission
BNFL	British Nuclear Fuels Limited
BNL	Brookhaven National Laboratory (DOE)
CFR	Code of Federal Regulations
CSB	Canister Storage Building (Hanford)
CVDF	Cold Vacuum Drying Facility
DBE	Design Basis Earthquake (DOE)
DNFSB	Defense Nuclear Facilities Safety Board (DOE Oversight)
DOE	U.S. Department of Energy
DWPF	Defense Waste Processing Facility (Savannah River Site)
EPRI	Electric Power Research Institute
FFTF	Fast Flux Test Facility (Hanford)
HCLPF	High Confidence Low Probability of Failure (Seismic Capacity)
HWVP	Hanford Waste Vitrification Project (Hanford)
IBC	International Building Code
LBL	Lawrence Berkeley Laboratory (DOE)
LLNL	Lawrence Livermore National Laboratory (DOE)
MCO	Multi-Canister Overpack
MMI	Modified Mercalli Intensity
NEHRP	National Earthquake Hazard Reduction Program
NFS	Nuclear Fuel Services
N-H	Newmark-Hall (NRC Consultants)
NPH	Natural Phenomena Hazards
NRC	U.S. Nuclear Regulatory Commission
PC	Performance Category (DOE)
PGA	Peak Ground Acceleration
PNL	Battelle Pacific Northwest Laboratory (DOE)
PSHA	Probabilistic Seismic Hazard Analysis
RG	U.S. Nuclear Regulatory Commission Regulatory Guide
RL	Richland Operations Office (DOE)
RU	Office of Radiological, Nuclear, and Process Safety Regulatory Unit (DOE)
SAR	Safety Analysis Report
SER	Safety Evaluation Report
SLAC	Stanford Linear Accelerator Center (DOE)

Acronym	Definition
SNF	Spent Nuclear Fuel Project (Hanford)
SRD	Safety Requirements Document (TWRS-P)
SRS	Savannah River Site (DOE)
SSC	Structures, Systems, and Components
SSE	Safe Shutdown Earthquake (NRC)
SSI	Soil Structure Interaction
TERA	TERA Corporation (Now TENARA Corporation)
TWRS-P	Tank Waste Remediation System Privatization
UBC	Uniform Building Code
UHS	Uniform Hazard Spectra
USGS	U.S. Geological Survey
WHC	Westinghouse Hanford Company
WNP-2	Washington Nuclear Power Unit 2 (Operating Commercial Nuclear Power Plant)
WNYNSC	Western New York Nuclear Service Center
WVDP	West Valley Demonstration Project
WVNS	West Valley Nuclear Services

APPENDIX B. GLOSSARY OF SEISMIC-RELATED TERMS

Annual Probability of Exceedance

The annual probability of an earthquake event occurring with severity exceeding certain peak ground acceleration. It is the reciprocal of the average amount of time (in years) between consecutive events of the same or greater severity.

Blume Spectra

The response spectra proposed by John A. Blume and Associates for the Savannah River Site in the early 1980s. The Blume Spectra are anchored to a 0.2g peak ground acceleration, and have about a 5,000-year return period, or between PC 3 and PC 4 by current DOE standards.

Damping

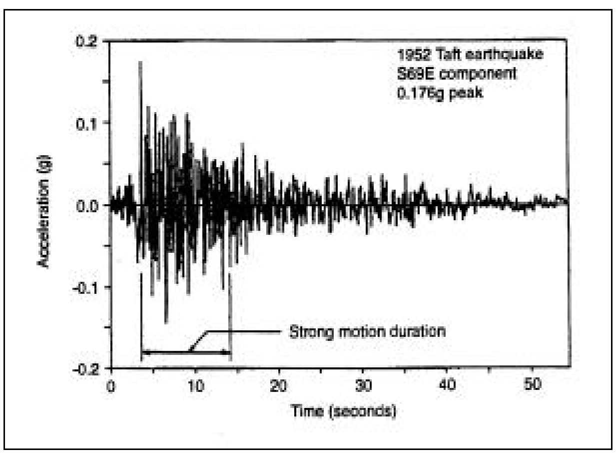
A means of modeling energy dissipation in structural systems. This is typically expressed as a damping ratio or as a percent of critical damping, the value of damping where vibration will not occur. For example, 5% damping would imply 5% of the critical damping. A value of 5% is typical for presenting response spectra.

DBE

Design Basis Earthquake is the earthquake used for design. It consists of horizontal and vertical peak ground acceleration and response spectra for various damping ratios.

Duration

The total time of ground shaking from the arrival of seismic waves until the return to ambient conditions. Much of this time is at relatively low shaking levels that have little effect on structural response and damage potential. As a result, a parameter termed "strong motion duration" has been defined for the purpose of evaluating seismic response and for assessing the potential for structural damage due to earthquakes. See the figure below.

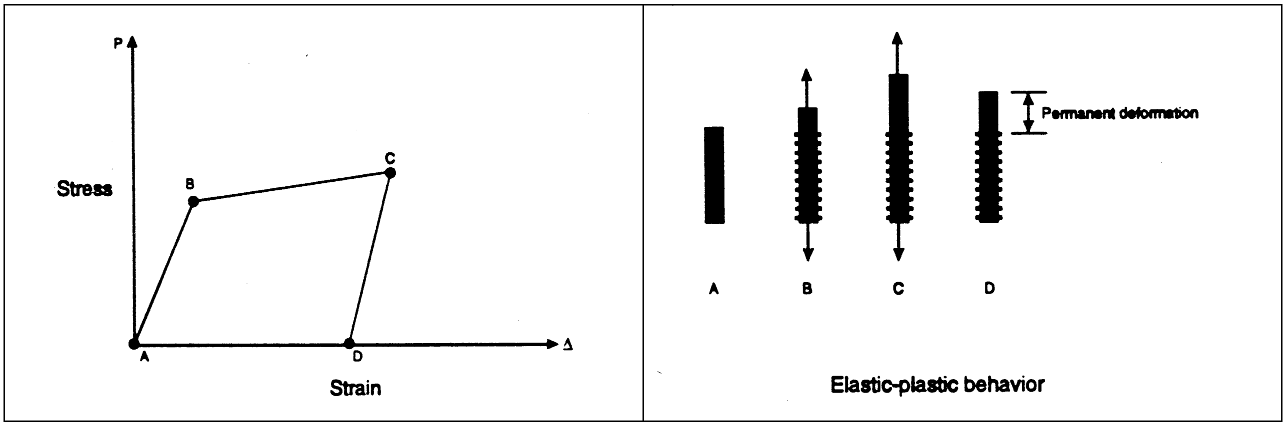


Elastic

Structural response wherein the strain (or deformation) path is the same for loading as it is for unloading; i.e., the strain (or deformation) returns to zero when the load is released.

Elastic-Plastic

A nonlinear, inelastic structural analysis (or response) in which the relationship between stress and strain (or force and deflection) is represented by a bilinear model, as shown below.



Free Field Motion

Earthquake ground motion not influenced by the presence of a structure.

Frequency and Period

Frequency is the number of times an SSC has completed a vibration cycle in a second. It is generally specified in unit of cycles/second or Hertz (Hz). Period is the reciprocal of frequency, and is reported in seconds.

Hanford Plant Standard

The document which specifies the criteria to be used for designing facilities at Hanford. The Standard was first prepared in 1957, and has been updated periodically as building codes change and as more data become available to define natural phenomena hazards at the site. The current criteria for design of Hanford facilities for protection against natural phenomena hazards in documented in Conrads 1997.

Hazard Exceedance Level

The annual probability of exceedance of hazard, such as an earthquake.

Important to Safety (TWRS-P Project)

Structures, systems, and components that serve to provide reasonable assurance that the facility can be operated without undue risk to the health and safety of the workers and the public. It encompasses the broad class of facility features addressed (not necessarily explicitly) in the top-level radiological, nuclear, and process safety standards and principles that contribute to the safe operation and protection of workers and the public during all phases and aspects of facility operations (i.e., normal operation as well as accident mitigation).

This definition includes not only those structures, systems, and components that perform safety functions and traditionally have been classified as safety class, safety-related or safety-grade, but also those that place frequent demands on or adversely affect the performance of safety functions if they fail or malfunction (i.e., support systems, subsystems, or components). Thus, these latter structures, systems, and components would be subject to applicable top-level radiological, nuclear, and process safety standards and principles to a degree commensurate with their contribution to risk. In applying this definition, it is recognized that during the early stages of the design effort all significant systems interactions may not be identified and only the traditional interpretation of important to safety (i.e., safety-related may be practical). However, as the design matures and results from risk assessments identify vulnerabilities resulting from nonsafety-related equipment, additional structures, systems, and components should be considered for inclusion within this definition.

Importance Factor

A factor used in the Uniform Building Code and used in DOE criteria for PC 1 and 2 SSCs. The Importance Factor is used to increase the design motion for essential facilities (or PC 2) over conventional facilities (or PC 1) by 25%.

Inelastic

Structural response wherein the strain (or deformation) path is different between loading and unloading. Generally, when the load is released, a nonzero residual strain or deformation remains.

In-Structure Response Spectra

Response spectra developed within a structure (for example, on a floor or a wall) for use in designing equipment or systems.

Linear Analysis

A structural analysis wherein the properties of the materials are modeled as constants, and, as a result, the deflections of the structure are directly proportional to the applied load.

Liquefaction

The loss of strength in saturated loose, cohesionless soils (such as sands and silts) as a result of pore water pressure increase induced by vibration, usually from earthquake shaking of sufficient amplitude and duration.

Magnitude

A measure of the size of an earthquake. Several scales are used to characterize the magnitude of an earthquake. The original magnitude was the Richter (or local magnitude, designated **ML**) scale, and was based on the deflection of a Wood-Anderson Seismograph at a specific distance from the epicenter.

The Richter (or local) magnitude, **ML**, was developed for use in Southern California, and estimates the energy of shallow earthquakes from the maximum amplitude of the seismogram recorded on a specific type of seismometer located 100 km from the epicenter and sitting on firm ground.

The second magnitude, initially developed by Richter and Gutenberg, **MS**, takes advantage of the fact that seismographs recording distant earthquakes are dominated by surface waves with a period of about 20s (0.05 Hz). This magnitude measure may often be called surface-wave magnitude. Seismologists often use other magnitudes as well, such as:

m_b (Body-Wave Magnitude Scale)

One of the earthquake magnitude scales in use. It is the logarithm of the maximum seismographic amplitude of 1-Hz body waves.

M_W (Moment Magnitude Scale)

Another of the earthquake magnitude scales in use. It is the logarithm of the seismic moment, a function of the extent and amplitude of the break and of the strength of the earth at the point of rupture.

Mean

The average value of a sample or population, numerically, the sum of the values divided by the number of values.

Median

The middle value. A value from an ensemble (or population) selected such that 50% of the population are larger and 50% are smaller, regardless of how much higher or lower.

Natural Phenomena Hazards

Acts of nature, which include earthquakes, extreme winds and tornadoes, floods, lightning, and volcanic eruptions. Design criteria have been developed to mitigate the effects of natural phenomena hazards on structures, systems, and components.

Nonlinear Analysis

A structural analysis wherein the properties of the materials are dependent on strain (or load) levels (material nonlinearity), or where the structural response is dependent on deflection (geometric nonlinearity), and, as a result, the deflections of the structure are not proportional to the applied load.

Peak Ground Acceleration

Maximum ground acceleration occurring during an earthquake.

Performance Category (PC)

A classification, using a graded approach, in which structures, systems, or components in a category are designed to ensure similar levels of protection (i.e., that they meet the same performance goal) during natural phenomena hazard events.

DOE has established five performance categories as follows:

> PC 0 is used where no special consideration for NPH design are needed. An example is a component where failure would not cause a safety or mission problem, and fixing the failed component is inexpensive.
>
> PC 1 is used to maintain occupant safety by preventing major structural damage or collapse. A conventional facility such as an office building would be placed in PC 1.
>
> PC 2 is used to maintain occupant safety and also have continued operation with minimum interruption. Examples of essential facilities are firehouses, emergency communications centers and emergency power facilities.
>
> PC 3 is a category for facilities housing operations involving nuclear or hazardous chemical materials designed to perform a confinement function. Generally, this category is applied to non-reactor nuclear facilities where the material form and/or the energy source is insufficient to cause widespread release from a breached confinement barrier.
>
> PC 4 is a category for facilities that house hazardous materials which have a high-energy source to spread them over a large area in the event of a containment or confinement breach, such as in a nuclear reactor.

DOE-Standard-1021 provides guidance on selection of performance categories for each structure, system, and component. DOE-Standard-1020 provides design criteria for each performance category.

Performance Goal

The annual probability of exceeding a specified level of damage. A qualitative description of expected behavior for systems, structures, and components when subjected to a specific natural phenomenon event. It is delineated in detail in DOE Standard 1020, and used to balance design criteria for various NPH events.

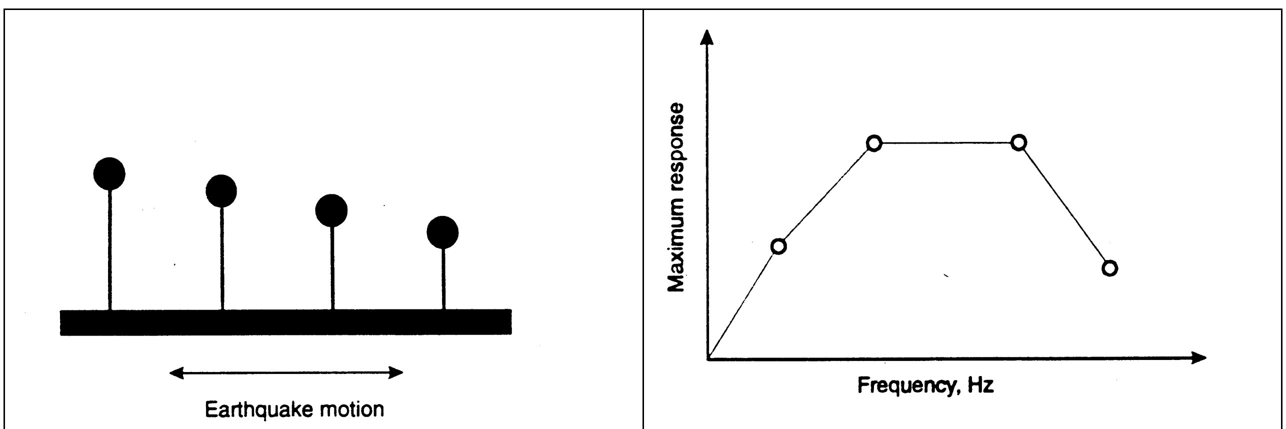
Regulatory Guides

A series of Guides produced by NRC that indicates acceptable approaches for designing commercial nuclear power plants. For example, Regulatory Guide 1.60 provides horizontal and vertical response spectra shapes for generic sites, and Regulatory Guide 1.61 provides damping values for various materials to be used in dynamic analysis.

Response Spectra

The maximum responses of a series of linear single-degree-of-freedom (SDOF) oscillators to input excitation, each oscillator having a different natural frequency. This is one method to quantify earthquake motion.

The response spectrum can be visualized by assuming a movable base, as shown in the figure below. Fixed to the base is a series of cantilever oscillators, each with the same mass and damping ratio but of different support lengths. Thus, each oscillator has a unique frequency, *w*. The length of the oscillators decreases to the right, with a corresponding increase in natural frequency. If the base is moved through the earthquake ground motion and if the maximum response of each oscillator is recorded, a response spectrum curve can be developed, as shown in the figure below.



Generation of response spectrum

Return Period

Average time between consecutive events of the same or greater severity. Equal to 1/annual probability of exceedance of hazard.

Safety Design Class (TWRS-P Project)

Structures, systems, or components that, by performing their specified safety function, prevent workers or the maximally exposed member of the public from receiving a radiological exposure that exceeds the accident exposure standards defined in the Safety Requirements Document (BNFL 1998a). Safety Design Class also applies to those features that by functioning, prevent the worker or maximally exposed member of the public from receiving a chemical exposure that exceeds the Emergency Response Planning Guidelines (ERPG-2) chemical release standard. Those features credited for the prevention of a criticality event are also designated as Safety Design Class.

Safety Design Significant (TWRS-P Project)

Structures, systems, and components needed to achieve compliance with the radiological or chemical exposure standards for the public and workers during normal operation; and SSCs that can, if they fail or malfunction, place frequent demands on, or adversely affect the function of Safety Design Class SSCs.

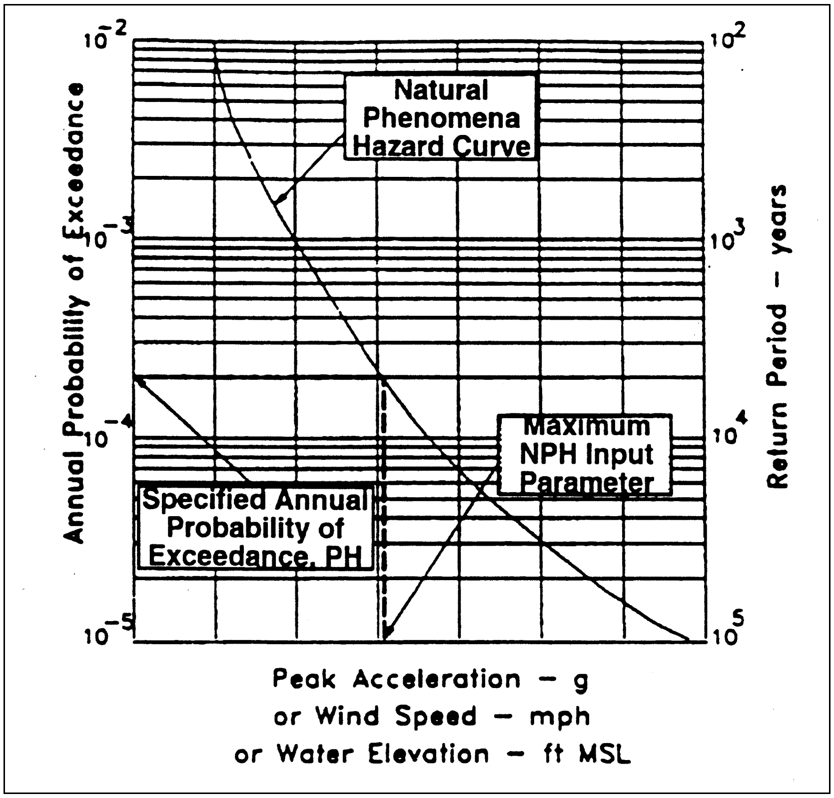
SDOF (Single Degree of Freedom)

A dynamic analysis model of an SSC is said to possess an SDOF if the dynamic characteristics of the SSC is represented by a single mass point such that the mass point can move or rotate in only one direction when the SSC is subjected to a time-varying force, acceleration, velocity, or displacement input.

Seismic Hazard Curves

A plot characterizing the seismic hazard at a specific site by giving the return period or annual probability of exceedance as a function of the peak ground acceleration or any other ground motion parameter (e.g., peak ground velocity, peak ground displacement, spectral acceleration at a given frequency) used to characterize the level of earthquake ground motion at this site. The mean seismic hazard curve is used to determine the Design Basis Earthquake.

The earthquake (or wind loads or flood levels) used for the design or evaluation of DOE facilities are based on hazard parameters from these curves at selected annual probabilities of exceedance, as illustrated in the figure below. There is considerable uncertainty in natural phenomena hazard curves, which is not indicated by the single curve shown in the figure.



Soil-Structure Interaction (SSI)

Interaction of the structure with supporting soil during dynamic loading. SSI affects structural response in the following ways:

> Changes the foundation-driving force from that of the free-field motion due to the presence of the foundation.
>
> Lowers modal frequencies of the soil-structure system due to foundation compliance.
>
> Modifies amplitude in various modes by dissipating energy as a result of wave propagation away from the base of the foundation and hysteretic soil response.

Spatial Interaction

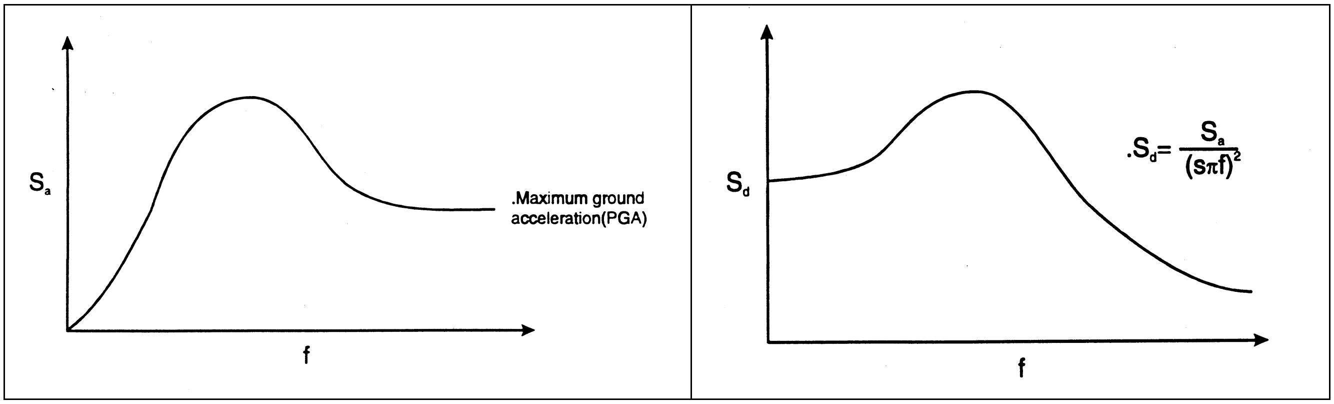
Term used to indicate an interaction between two or more SSCs. The interaction can be impact by an adjacent object, falling of an overhead object, flooding due to pipe or tank leaks or breaks, or fire.

Spectral Acceleration or Spectral Displacement

The value of acceleration or displacement from a response-spectra plot at a selected frequency or period.

The spectral acceleration curve approaches peak ground acceleration at high frequencies.

The spectral displacement curve approaches peak ground displacement at zero frequency.



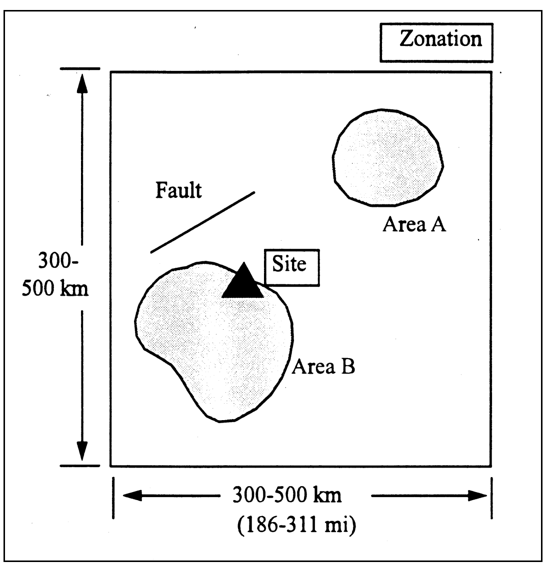
Time History

The variation of a parameter with time. The parameter can be displacement, velocity, acceleration, force, or stress.

TERMS RELATED TO PROBABILISTIC SEISMIC HAZARD ASSESSMENT

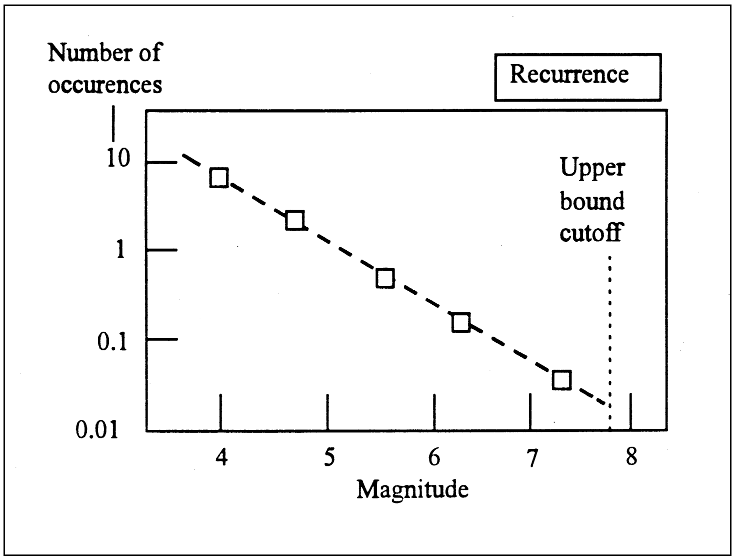
Zonation

The process of defining regions which are potential sources of earthquakes. These may be area sources or line sources, such as faults. Their location with respect to the site is described on a map, as shown below.



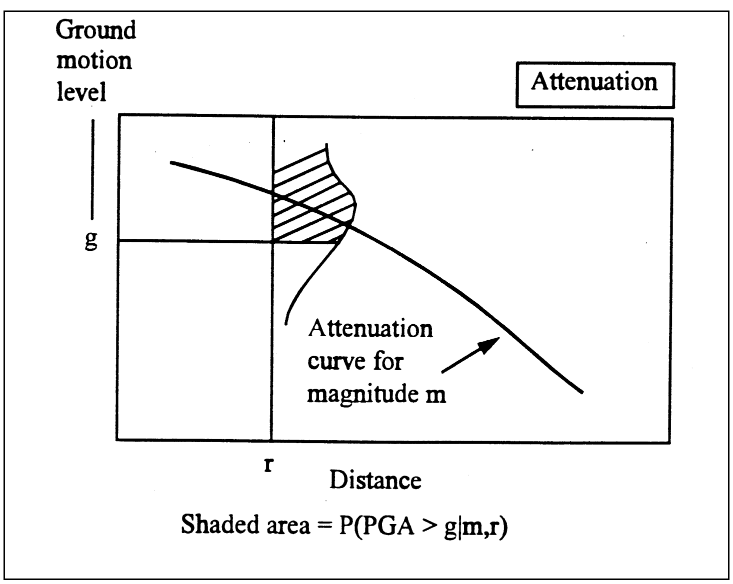
Recurrence

Associated with each zonation is a description of the frequency with which each event can occur. This is displayed as a recurrence relationship, as shown below. It describes how many earthquakes of each magnitude are to be considered in the hazard model.



Attenuation

The third element of probabilistic seismic hazard assessment is defining the attenuation relationship that describes how ground motion at the source is transmitted to the site. This is shown below.



The probabilistic seismic hazard assessment then integrates all previous material to develop a seismic hazard curve and uniform hazard spectra.